AFWAL-TR-88-1055
Volume II

GROWTH OF GALLIUM ARSENIDE USING ION CLUSTER BEAM TECHNOLOGY

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September 1988

Final Report for Period February 1984 - February 1987

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6543

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This program was designed to study the feasibility of growing epitaxial GaAs thin films for subsequent application in electronic devices. Due to mechanical difficulties and design problems the technique of deposition via ionized clusters was not realized. Data collected is somewhat inconclusive. To answer the feasibility question further, work including modification of the hardware needs to be performed. To this point the techniques have been shown to be capable of growing single crystal GaAs, but the required electrical characteristics of the film are not present.

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EPI-TECH CORPORATION

FINAL REPORT

VOLUME II

TITLE : Growth of Gallium Arsenide using Ion Cluster Beam Technology

FOR : U.S. Air Force / AFWAL / XRPA AADR
Wright Patterson Air Force Base

CONTRACT NO : F33615-84-C-1562

CORPORATE OFFICIAL AND PROJECT COORDINATOR : Dr. Robert L. Adams
President, Epi-Tech Corporation

PRINCIPAL INVESTIGATOR : James M. Bennett
R & D Engineer, Epi-Tech Corporation

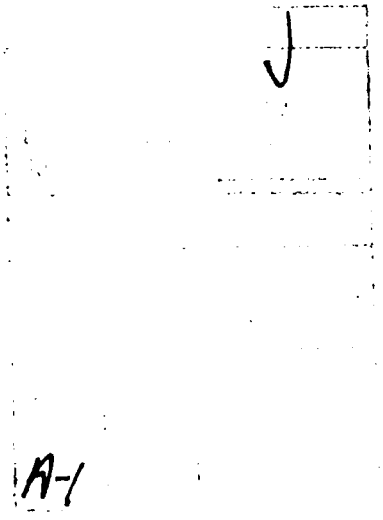


TABLE OF CONTENTS

VOLUME I

VOLUME II

APPENDIX A

NOZZLE LOG

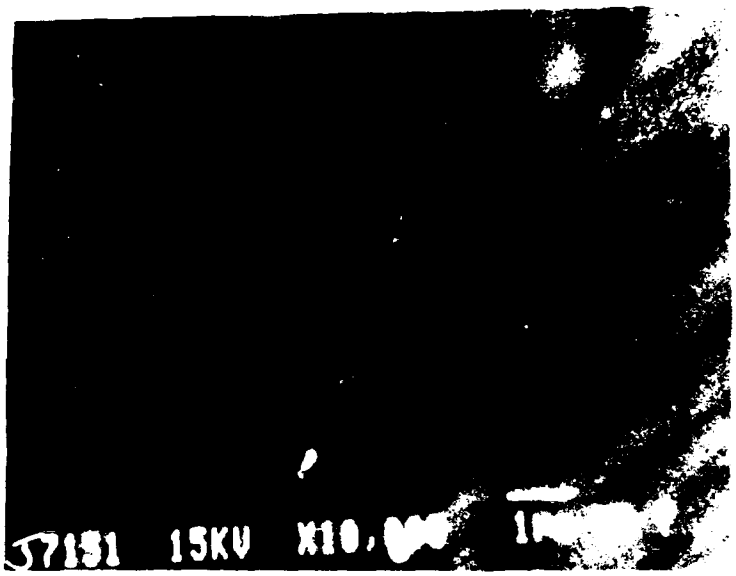
Nozzle No.	Description*
01	Large orifice 0.40 inch diameter
02	DeLeval type nozzle with 0.050 inch diameter throat at the vena contracta
03	DeLeval type nozzle with 0.100 inch diameter throat at the vena contracta
03A	DeLeval type nozzle with 0.100 inch diameter throat at the vena contracta and 0.10 inch extension
03B	LeLeval type nozzle with 0.100 inch diameter throat at the vena contracta and 0.50 inch extension
04	DeLeval type nozzle with 0.250 inch diameter throat at the vena contracta
05A	DeLeval type nozzle with 0.150 inch diameter throat at the vena contracta
05B	DeLeval type nozzle with 0.150 inch diameter throat at the vena contracta and 0.50 inch extension

*Nozzles with extensions have had the vena contracta moved the indicated distance from the top of the crucible. This was done to allow cooler nozzle temperatures and improve cluster formation.

APPENDIX B

RUN NO. 002

SAMPLE #002



Film
Surface

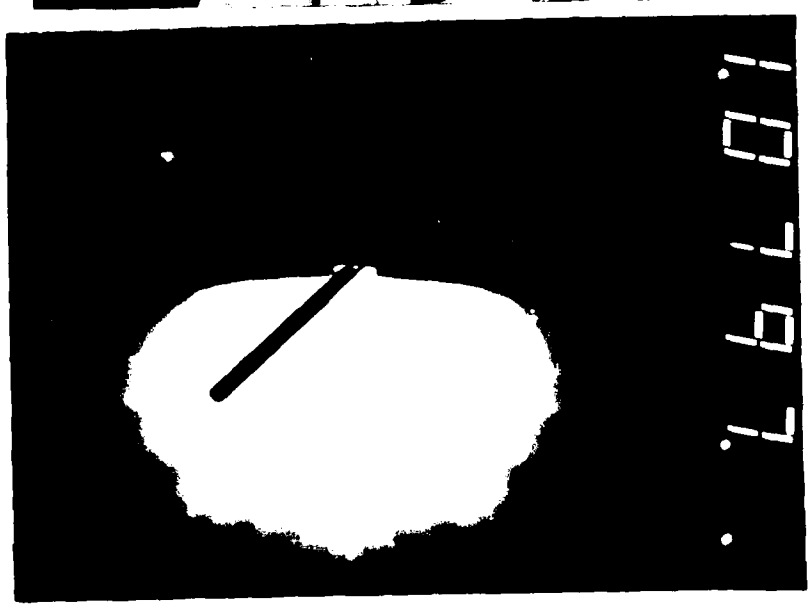
Cleave
Cross
Section

Film
Thickness
Approximately
2.4 μm

SAMPLE #002

ECP
(GaAs Substrate)

ECP
(ICB Film)



RHEED
(ICB Film)

SAMPLE #002

Substrate

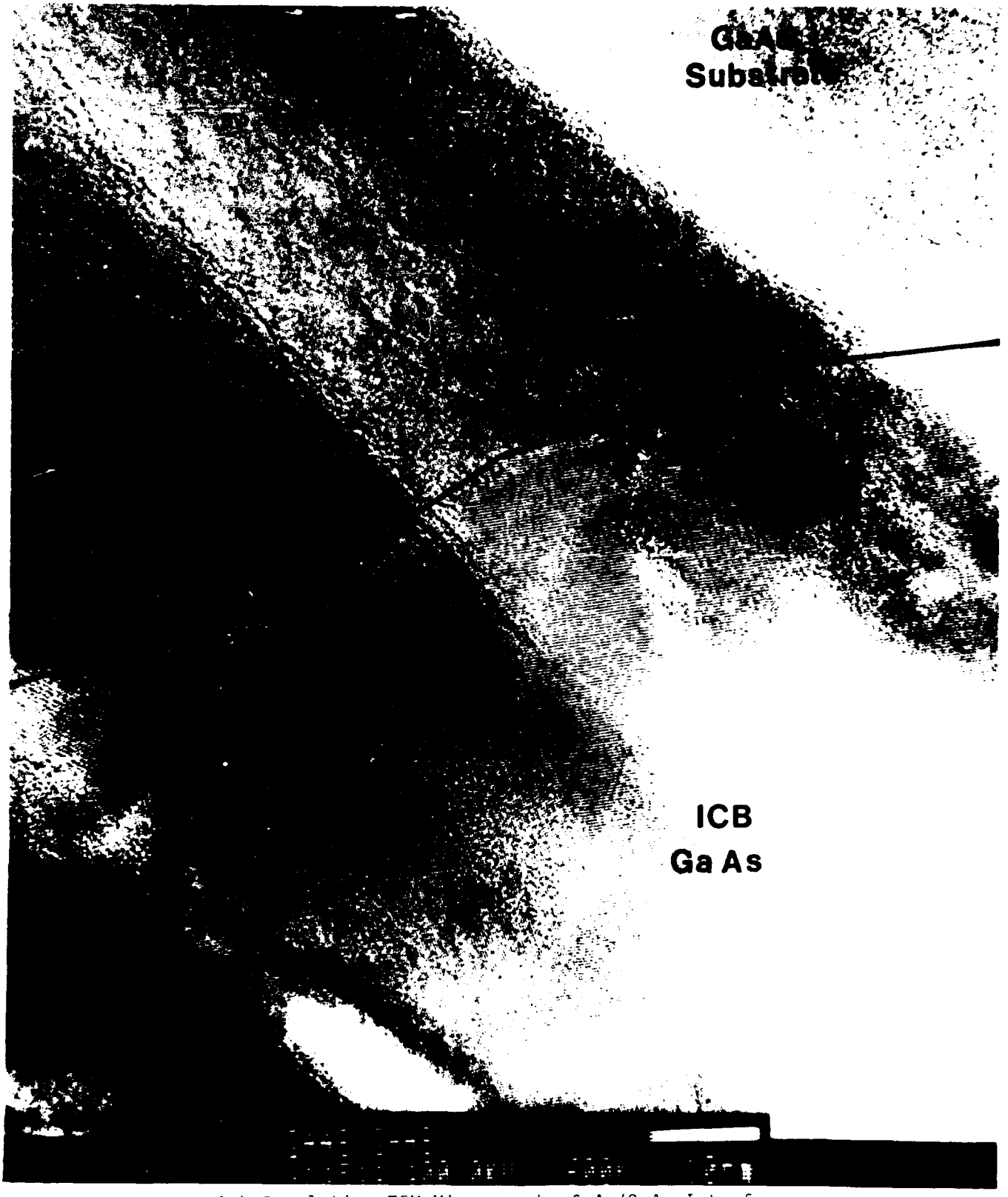
Interface

GaAs Film

x40,000
TEM Micrograph of Cross-Section

x36,000 TEM Micrographs in Direction Normal to Surface x36,000

SAMPLE #002

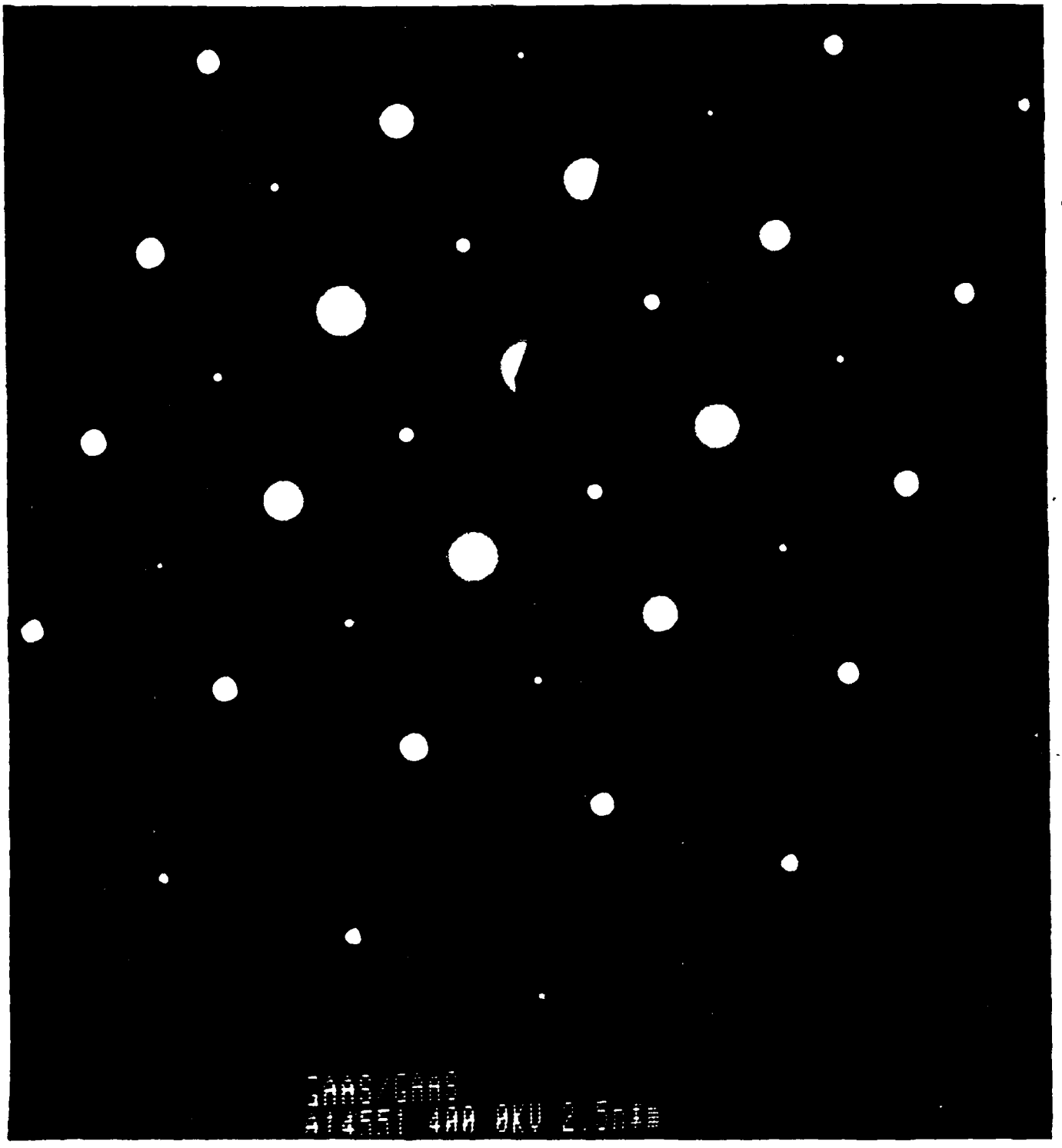


High Resolution TEM Micrograph of As/GaAs Interface

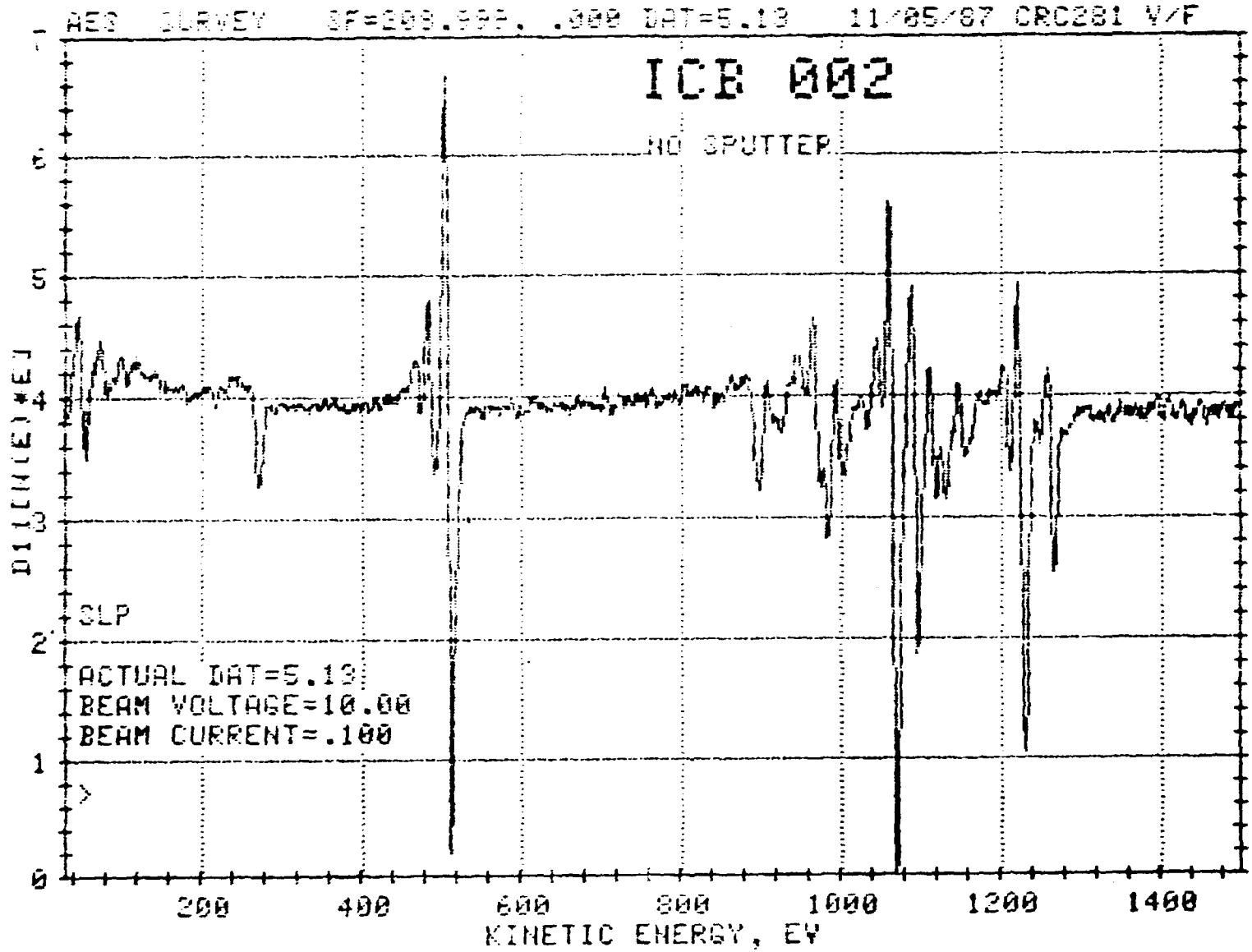
SAMPLE #002

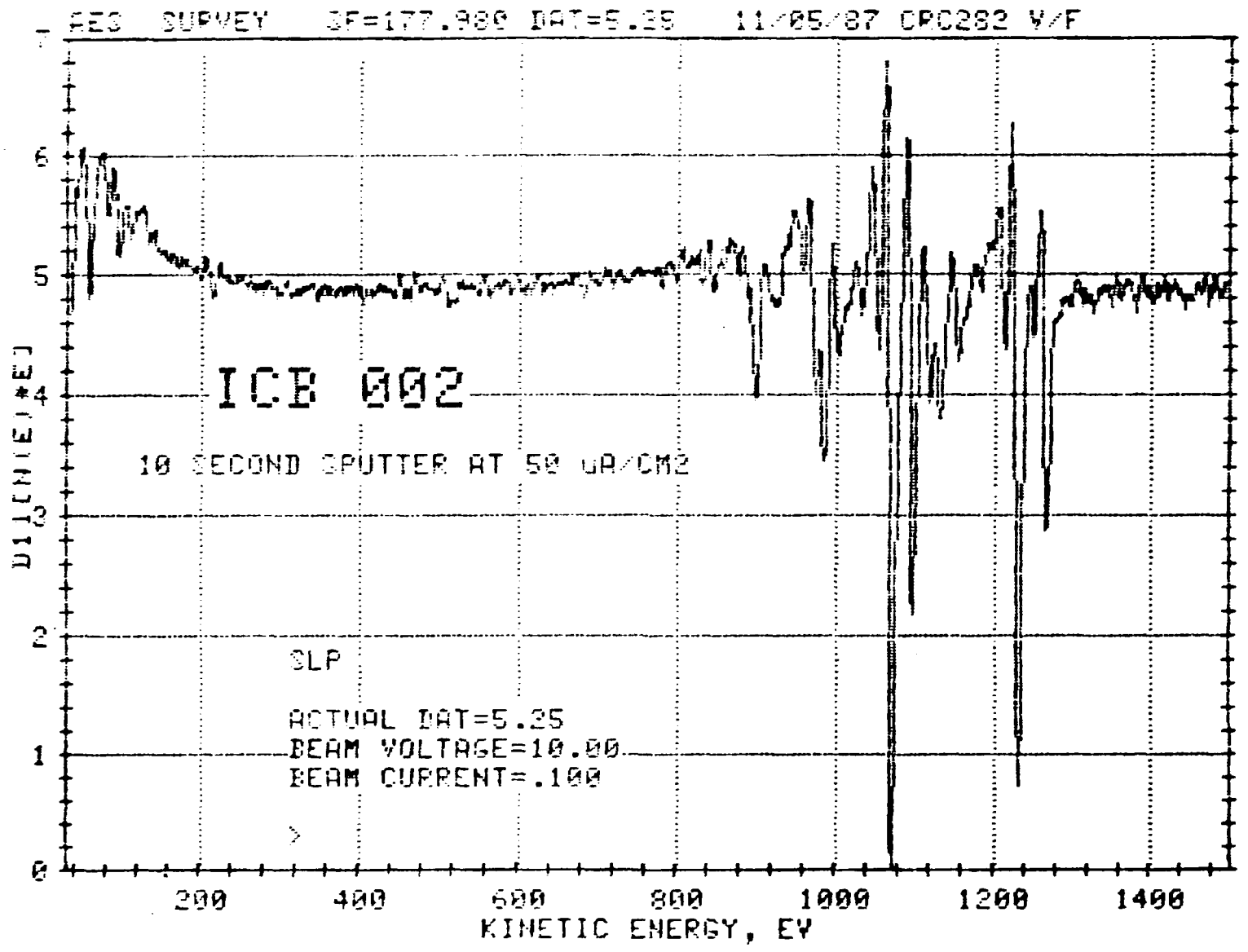
High Resolution TEM Micrograph of As/GaAs Interface

SAMPLE #002



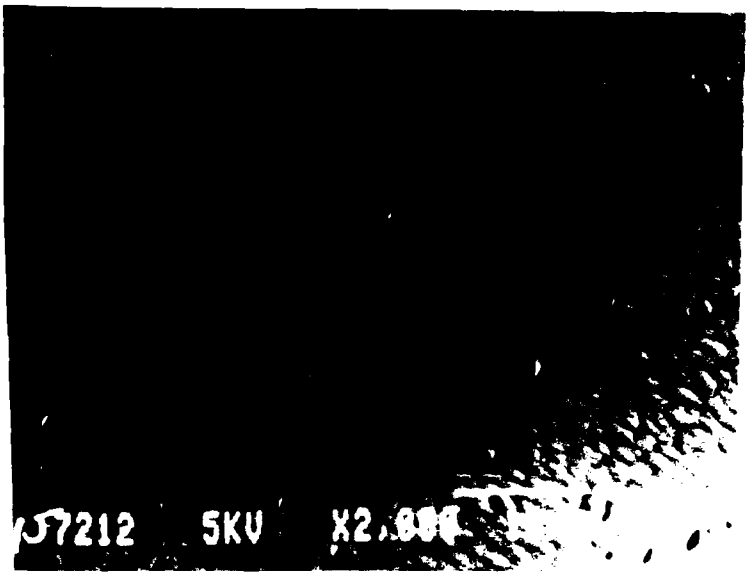
RHEED Pattern on (110) Cleaved Face


AES SURVEY SF=300.000, .000 DAT=5.13 11/05/87 CRC281 V/F
ICB 002
NO SPUTTER
DI(E)/DE*(E)
SLP
ACTUAL DAT=5.13
BEAM VOLTAGE=10.00
BEAM CURRENT=.100
>
0
1
2
3
4
5
6
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

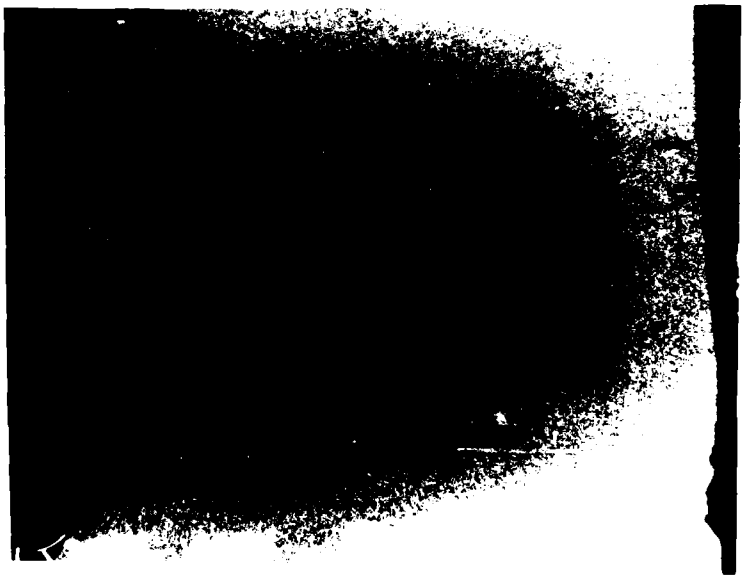

AES SURVEY SF=177.980 DAT=5.35 11/05/87 CRC282 V/F
ICB 002
10 SECOND SPUTTER AT 50 uA/CM2
SLP
ACTUAL DAT=5.25
BEAM VOLTAGE=10.00
BEAM CURRENT=.100
>
D1 [(N(E)*E)]
KINETIC ENERGY, EV
0
1
2
3
4
5
6
7
200
400
600
800
1000
1200
1400

RUN NO. 003

SAMPLE #003



Film
Surface



Cleave
Cross
Section

Fil
Thickness
Approximately ?

SAMPLE #003

ECP
(GaAs Substrate)

ECP
(ICD [illegible])

SAMPLE #003

x60,000

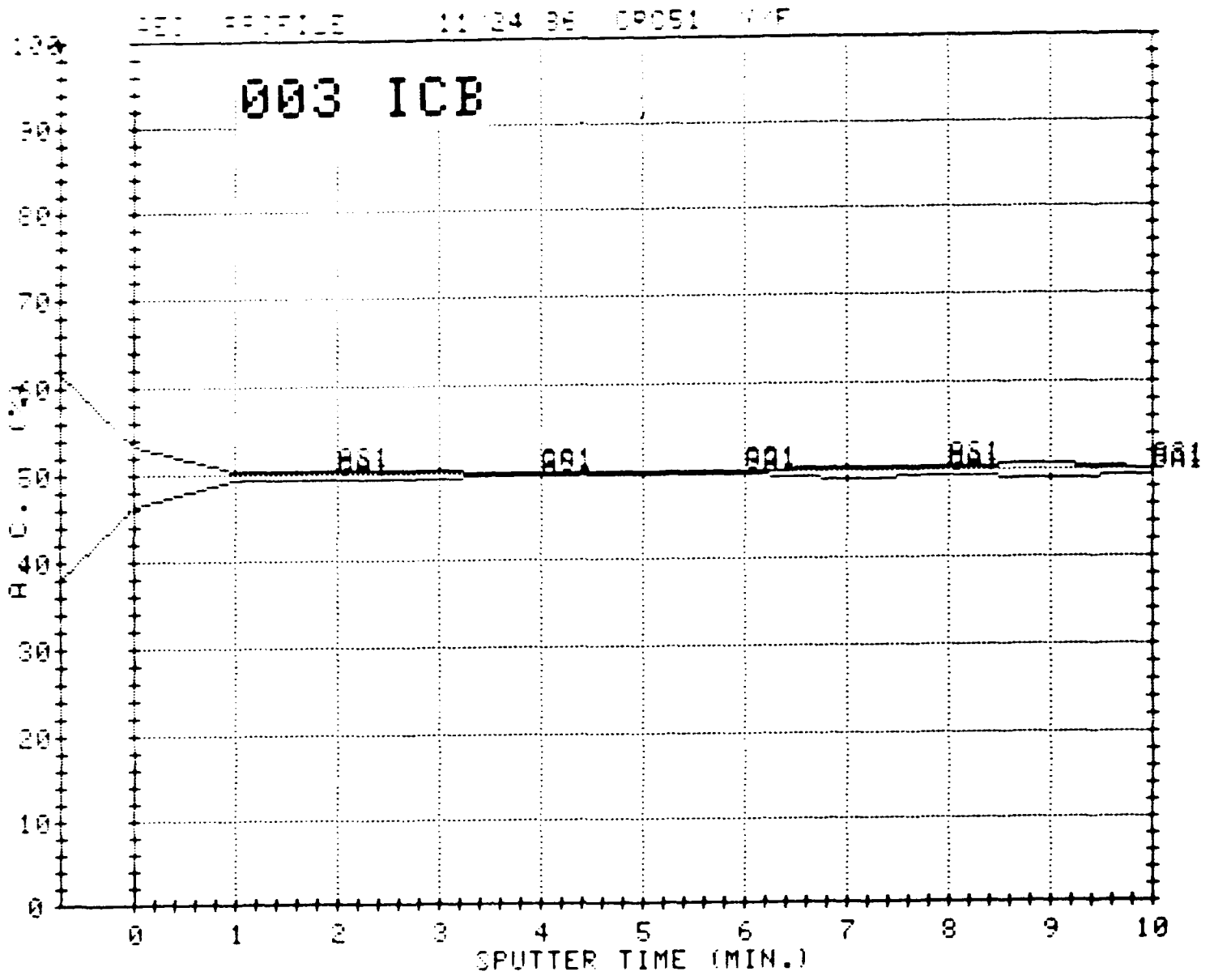
TEM Micrograph of Cross-Section

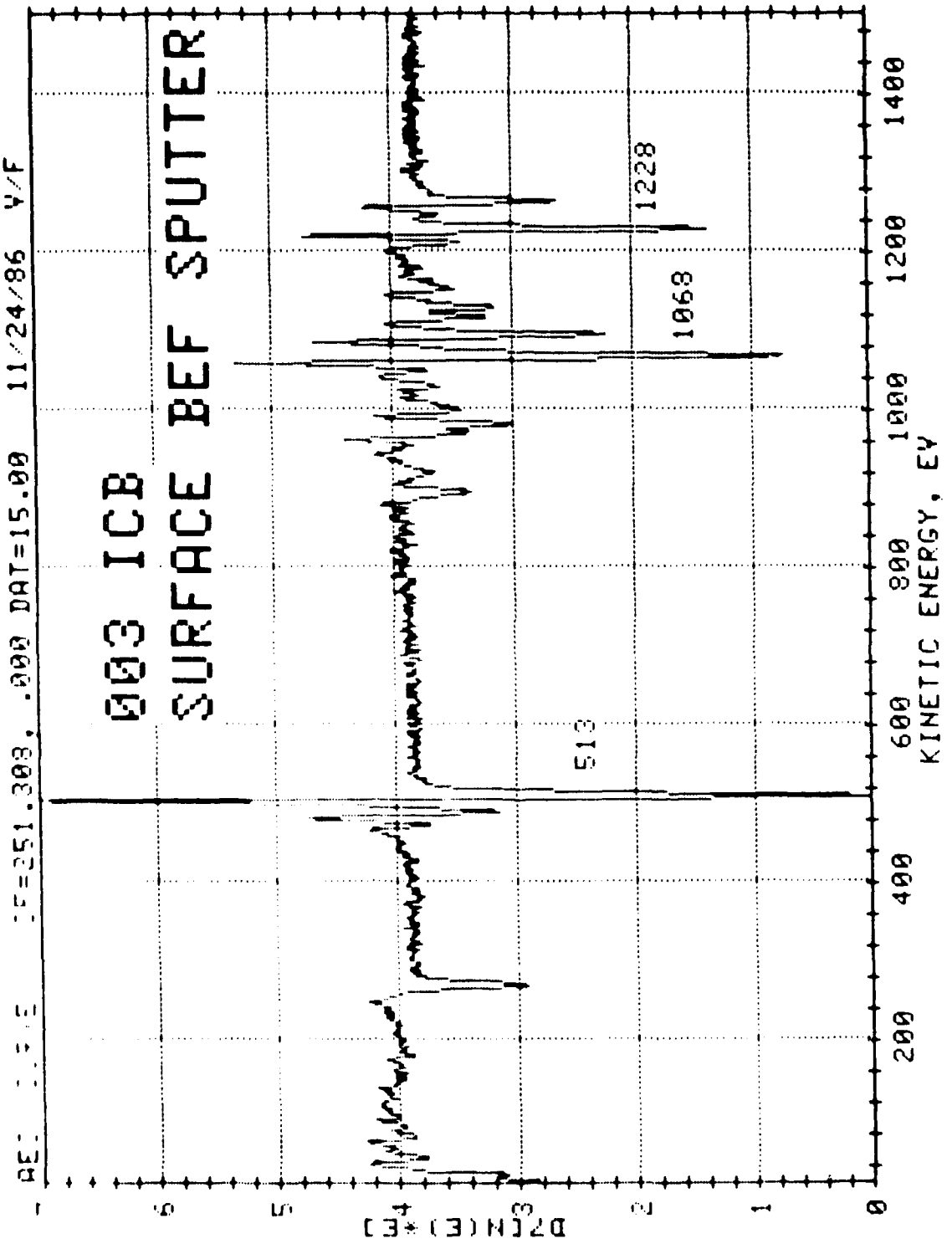
x36,000 x36,000

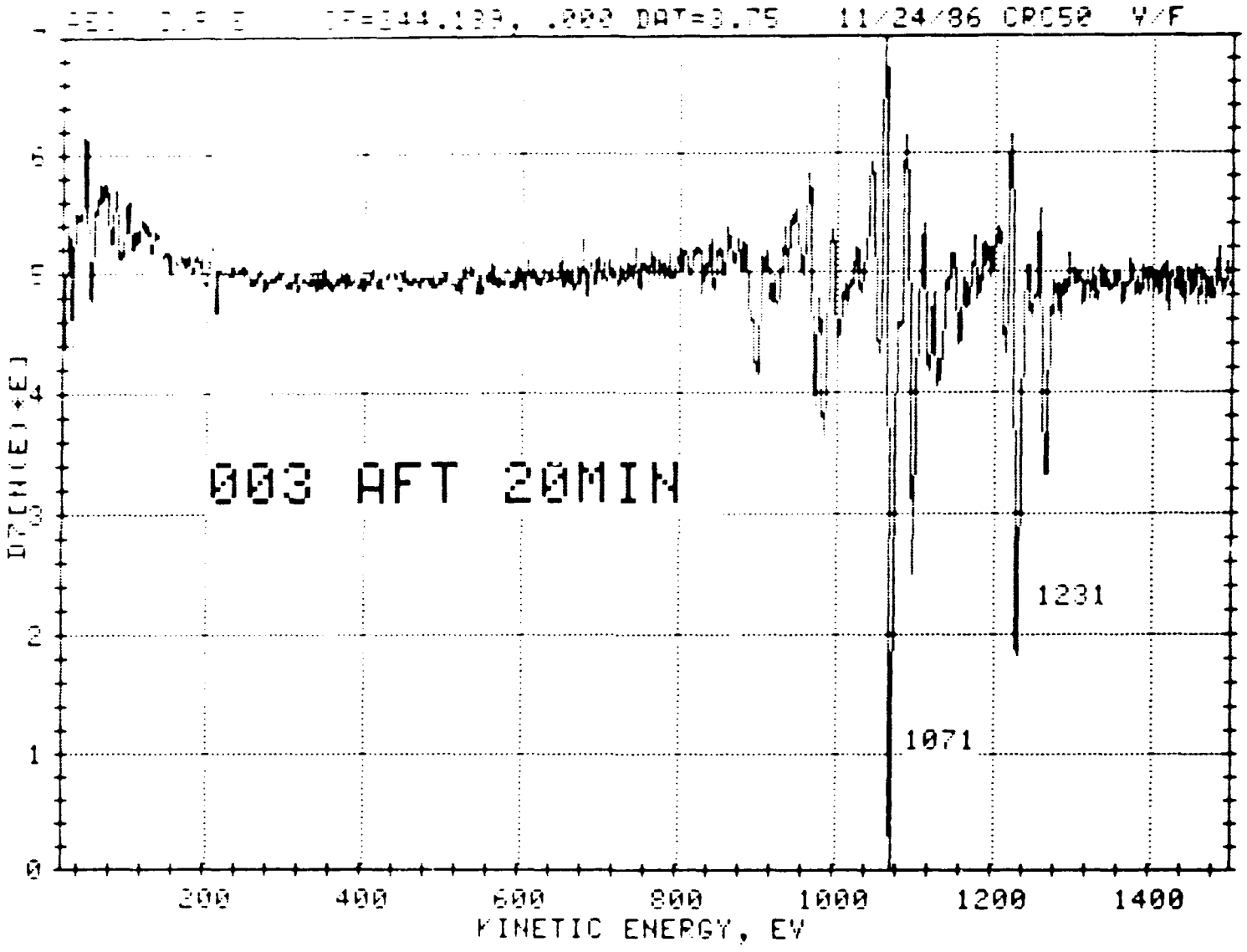
TEM Micrographs in Direction Normal to Surface

SAMPLE #003

High Resolution TEM Micrograph of GaAs/GaAs Interface

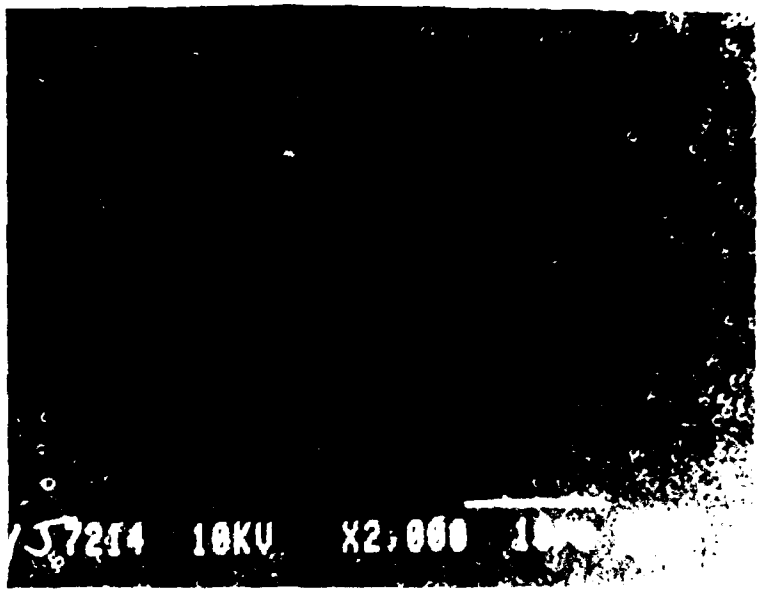

003 ICB
AA1
AA1
AA1
AA1
AA1
At C. (%)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
SPUTTER TIME (MIN.)


003 ICB
SURFACE BEF SPUTTER
11/24/86 Y/F
513
1068
1228
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
3
4
5
6

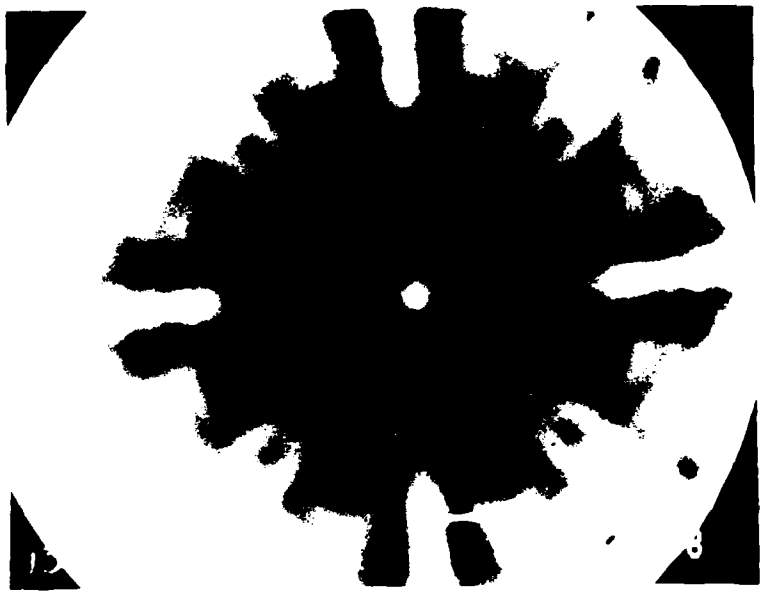

003 AFT 20MIN
1231
1071
D7[N(E)*E]
KINETIC ENERGY, EV
0
1
2
3
4
5
200
400
600
800
1000
1200
1400

RUN NO. 004

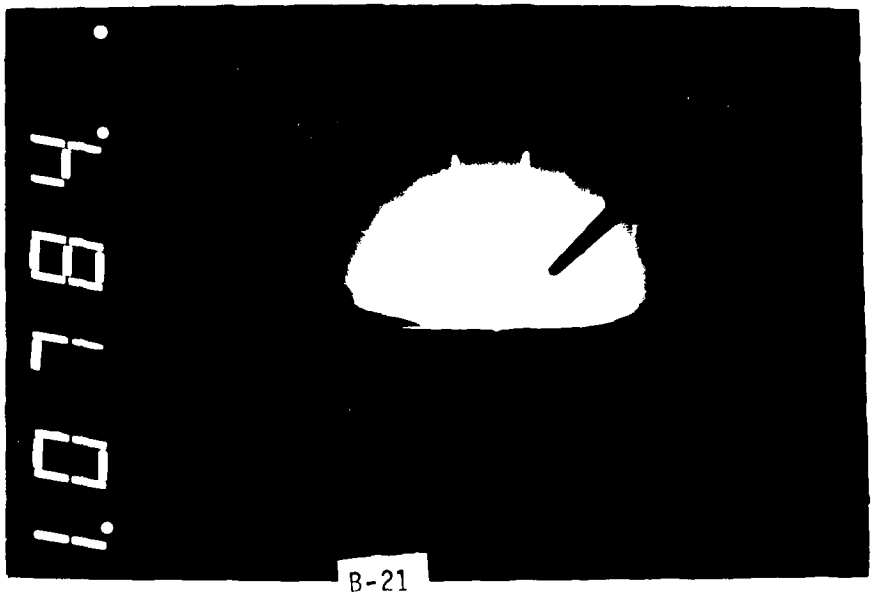
SAMPLE #004



SEM Micrograph of Film Surface

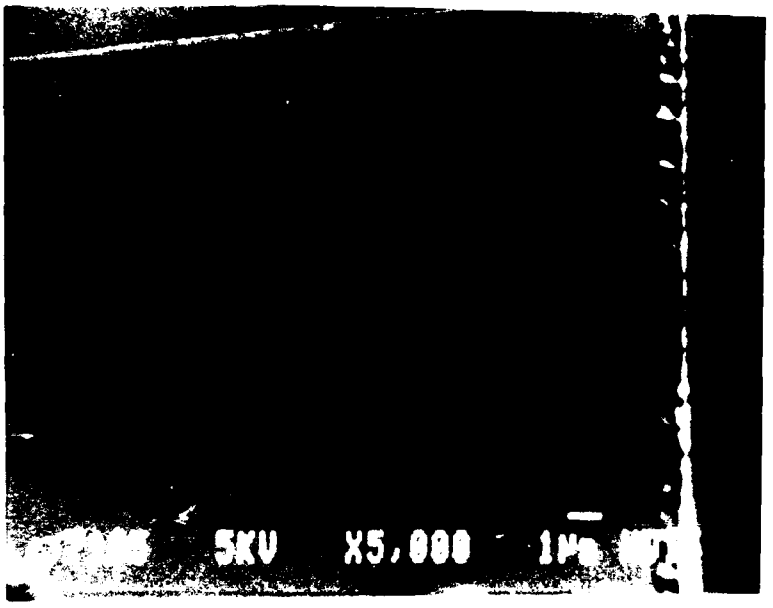


Electron Channeling Pattern from Film Surface



RHEED Pattern

SAMPLE #004



Cleave
Cross
Section

Film
Thickness
Approximately
0.9 μm

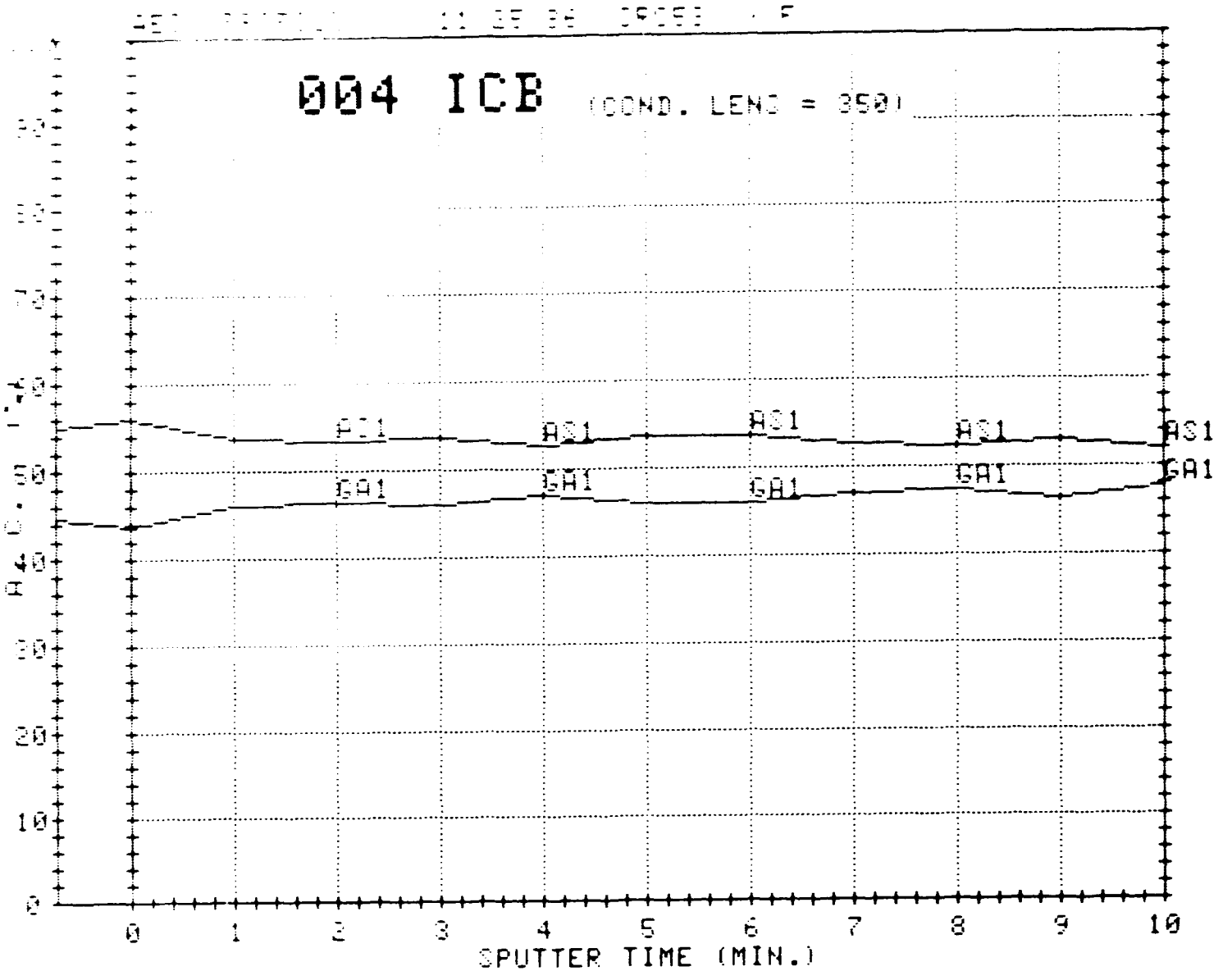
SAMPLE #004

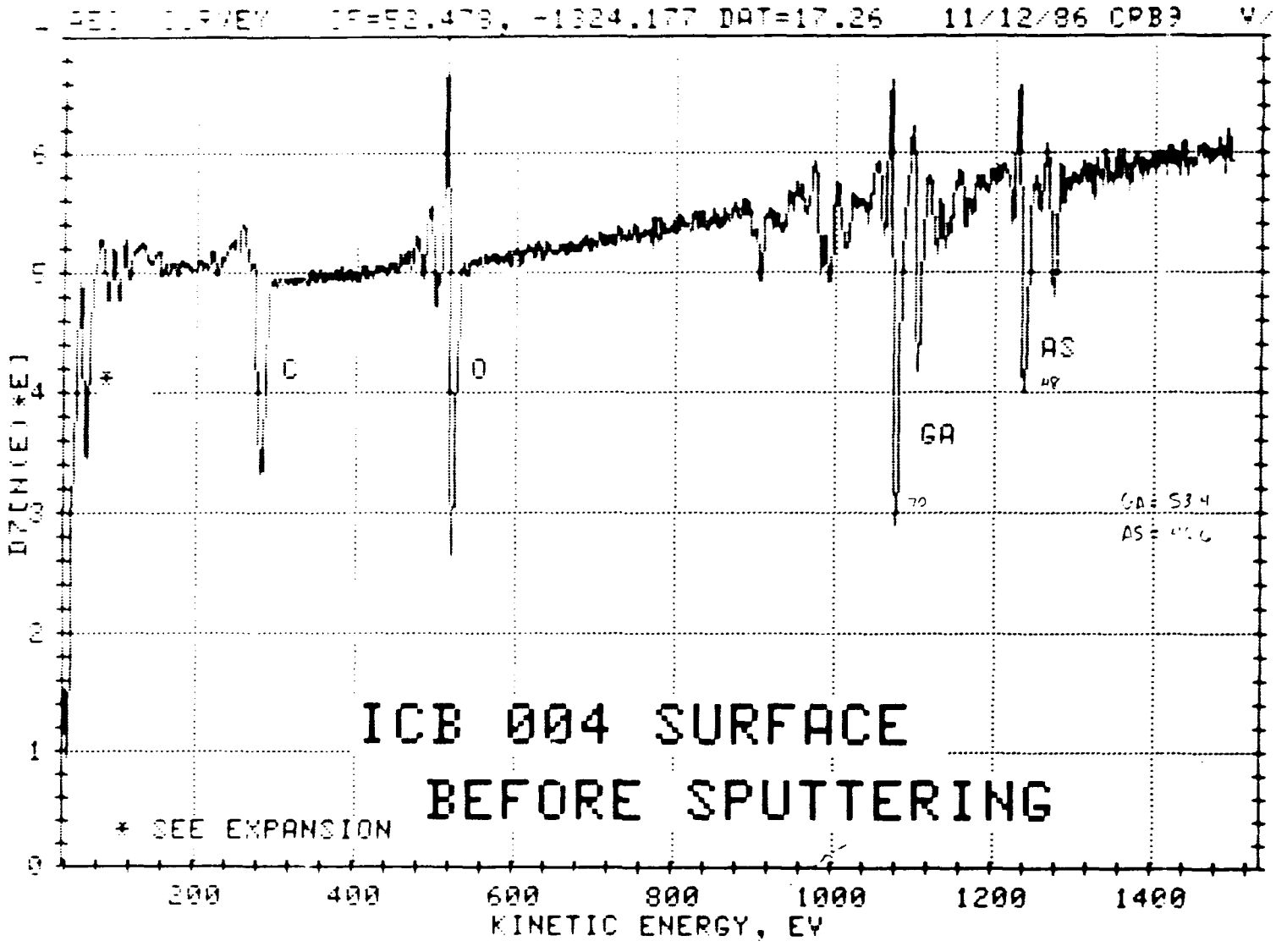
x36,000

TEM Micrograph of Cross-Section

x80,000

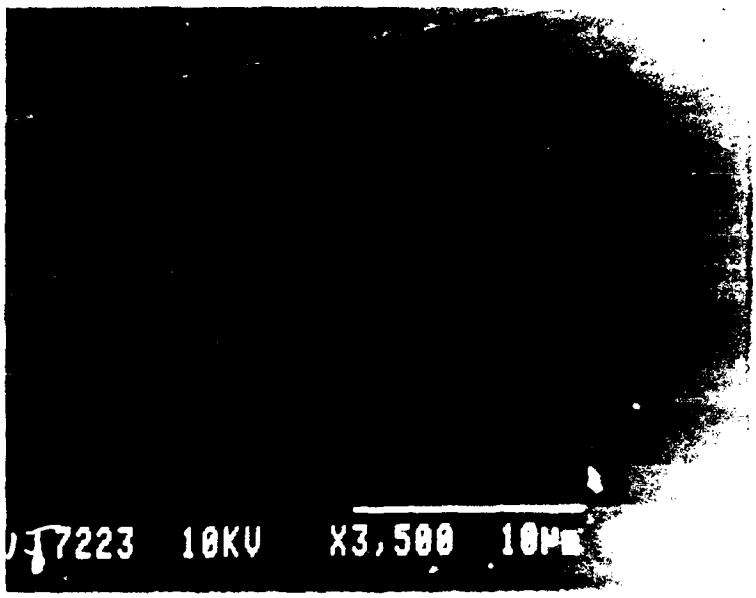
TEM Micrograph in Direction Normal to Surface


004 ICB
AS1
GA1
SPUTTER TIME (MIN.)
0
1
2
3
4
5
6
7
8
9
10


DIFF(N(E)*E)
KINETIC ENERGY, EV
300
400
600
800
1000
1200
1400
0
1
2
3
4
5
C
O
GA
AS
* SEE EXPANSION
ICB 004 SURFACE
BEFORE SPUTTERING

RUN NO. 005

SAMPLE #005

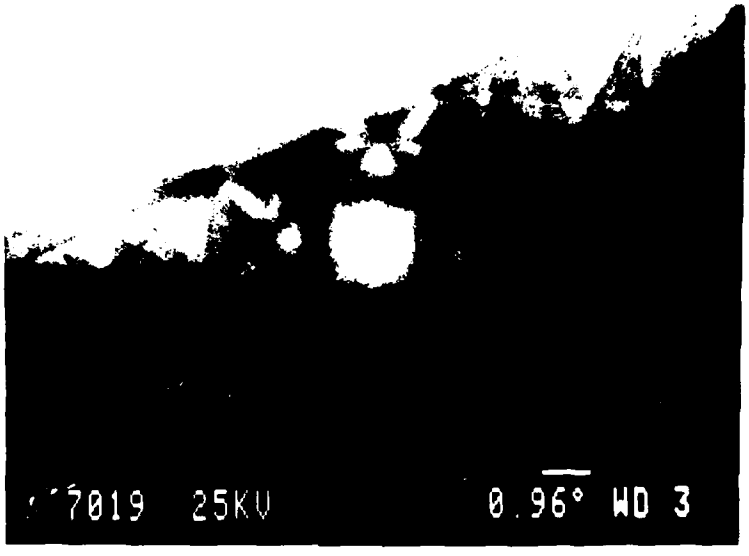


Film
Surface

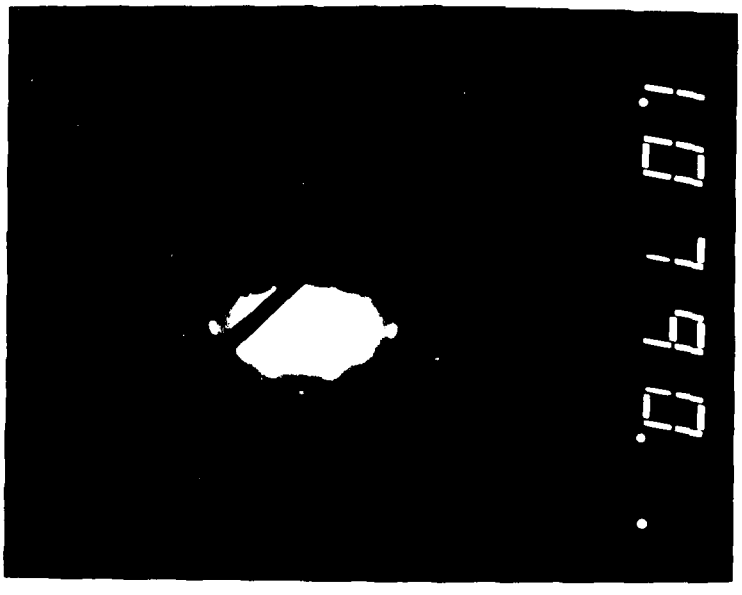
Cleave
Cross
Section

Film
Thickness
Approximately
0.6 μm

SAMPLE #005

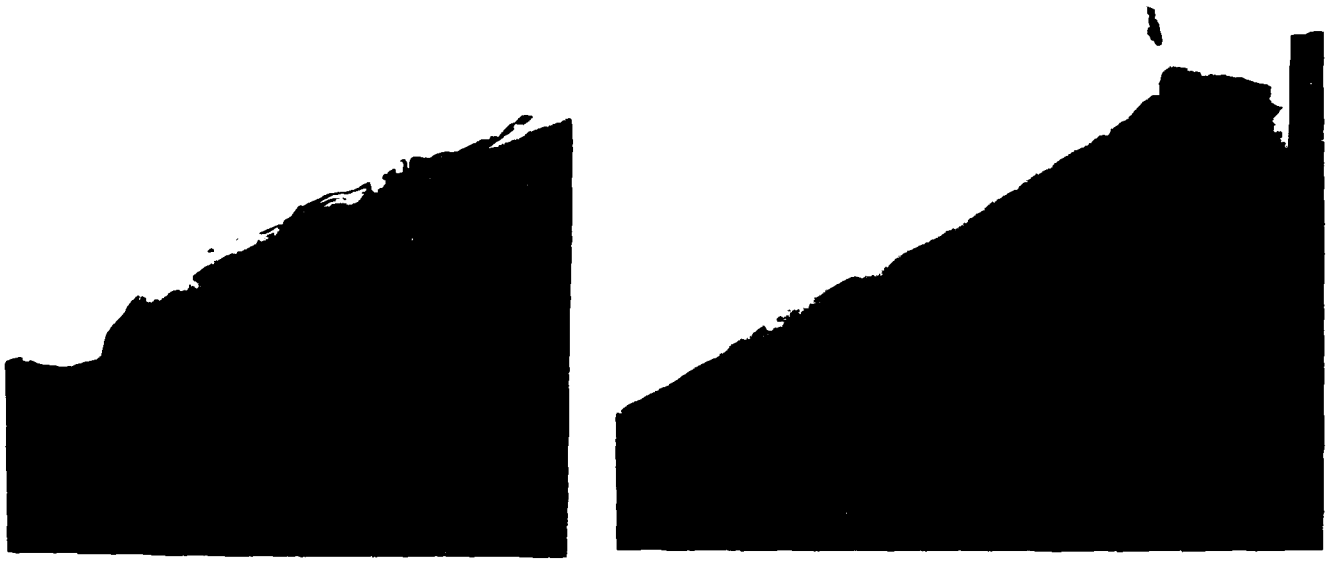


ECP
(GaAs
Film
Substrate)



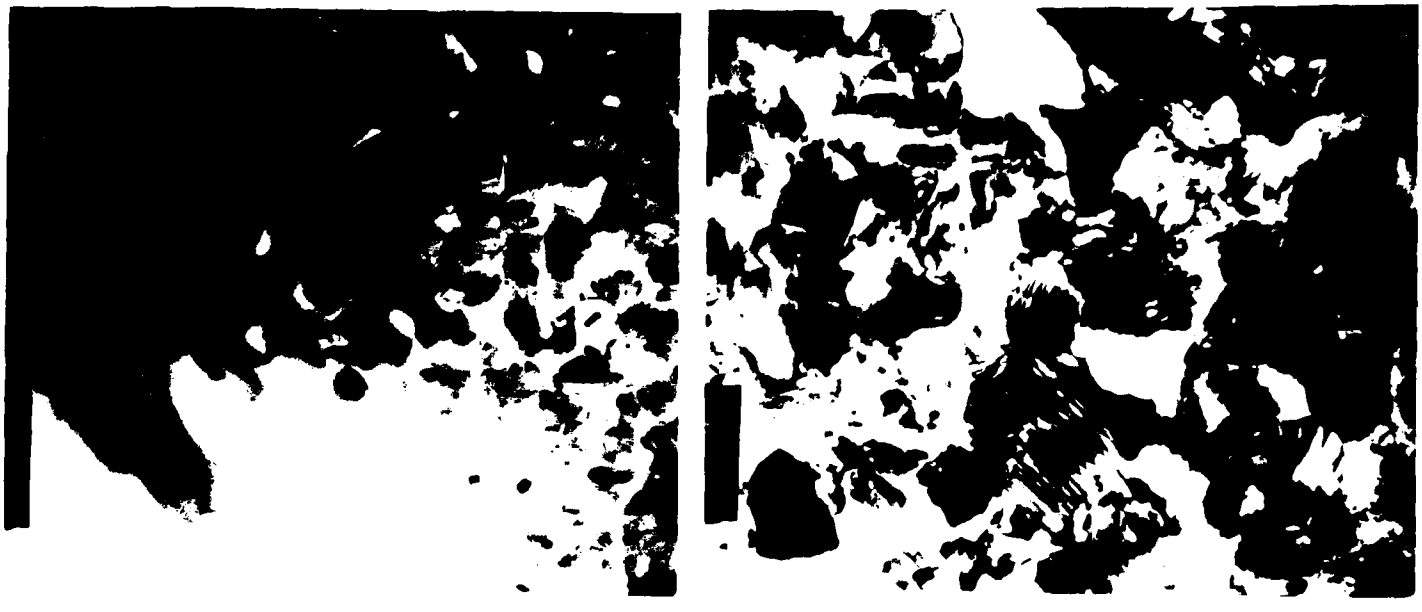
RHEED
(ICB Film)

SAMPLE #005



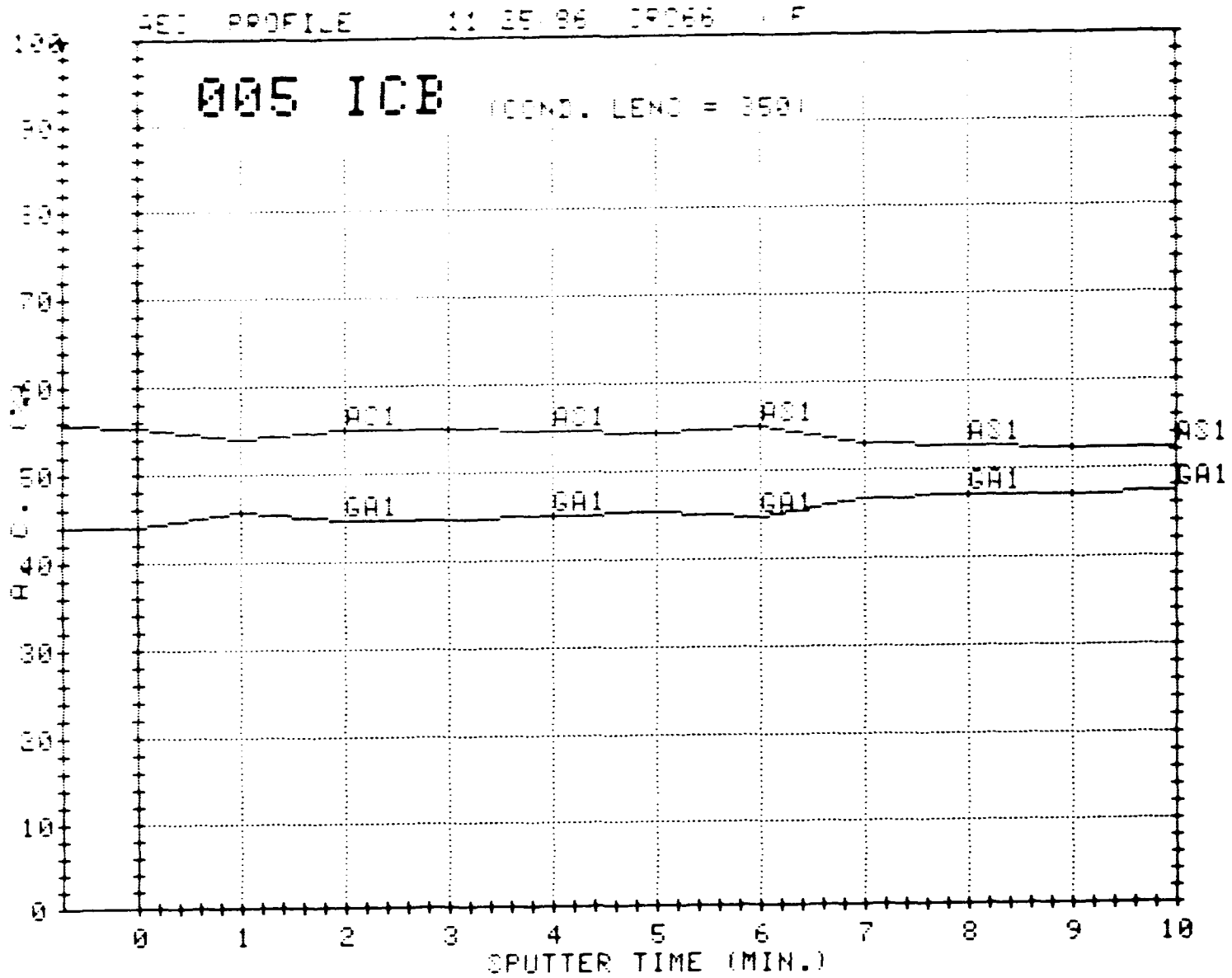
x13,000 x130,000

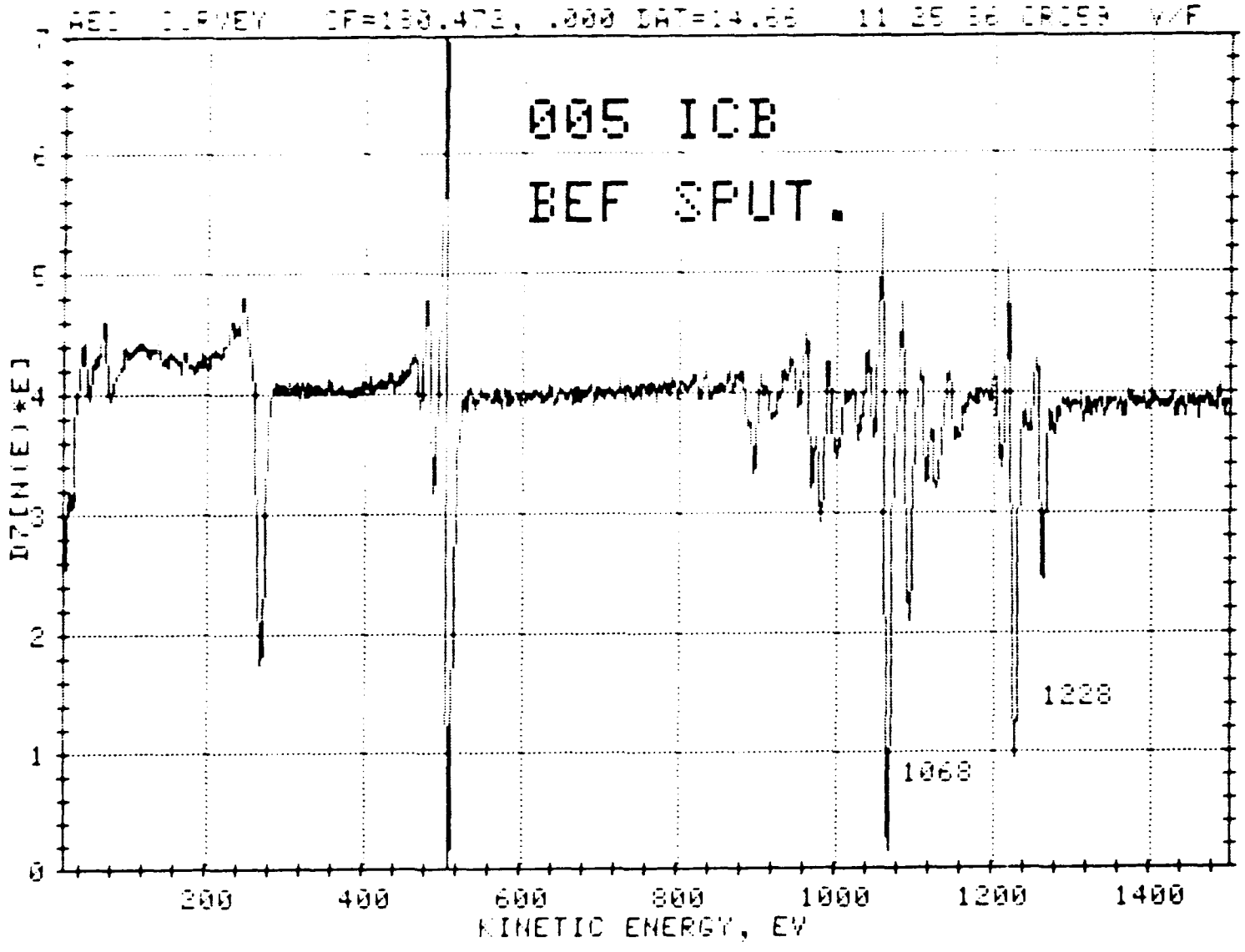
TEM Micrographs of Cross-Section



x80,000 x130,000

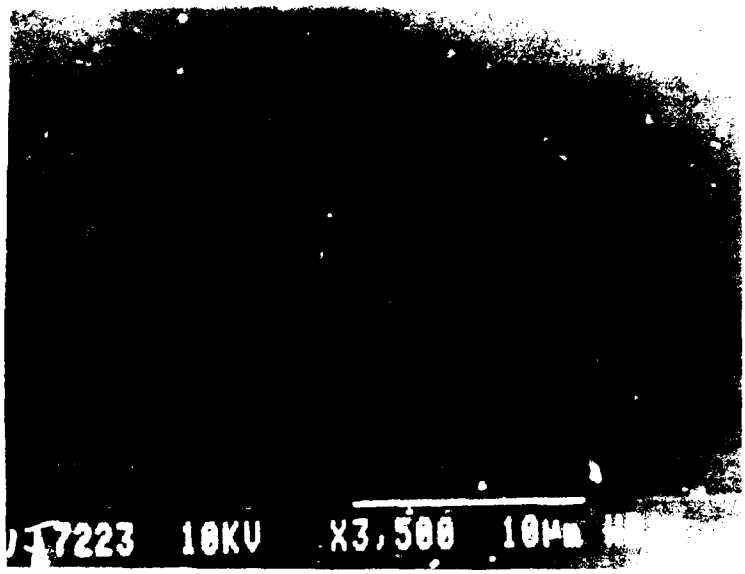
TEM Micrographs in Direction Normal to Surface


AEI PROFILE 11 25 86 I9066 : F
005 ICB (COND. LEND = 350)
AT. %
100
90
80
70
60
50
40
30
20
10
0
AG1
GA1
0 1 2 3 4 5 6 7 8 9 10
SPUTTER TIME (MIN.)

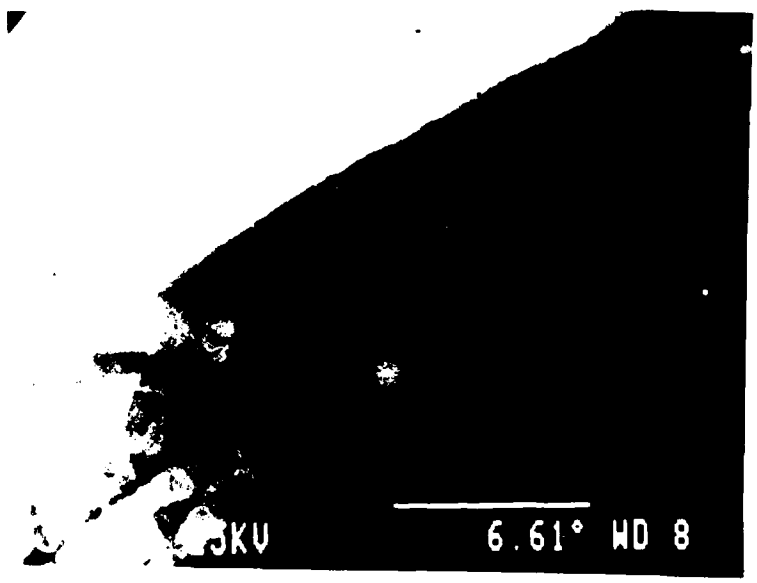

005 ICB
BEF SPUT.
1068
1228
D7[N(E)*E]
KINETIC ENERGY, EV
0
1
2
3
4
5
200
400
600
800
1000
1200
1400

RUN NO. 006

SAMPLE #006



SEM Micrograph of Film Surface



Electron channeling pattern taken near wafer edge. The sharp pattern emanates from the exposed substrate surface. The ICB film (top) does not yield a channeling pattern.

SAMPLE #006

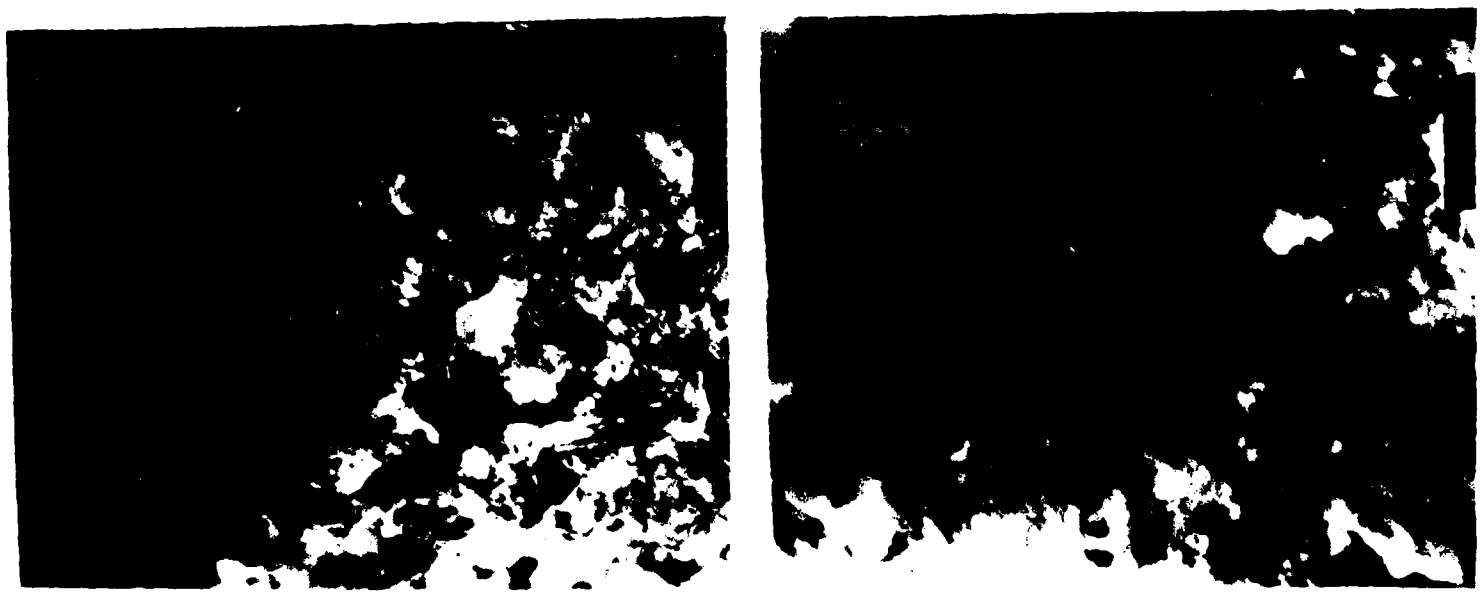
Cleave
Cross
Section

Film
Thickness
Approximately
0.8 μm

SAMPLE #006

x17,000 x80,000

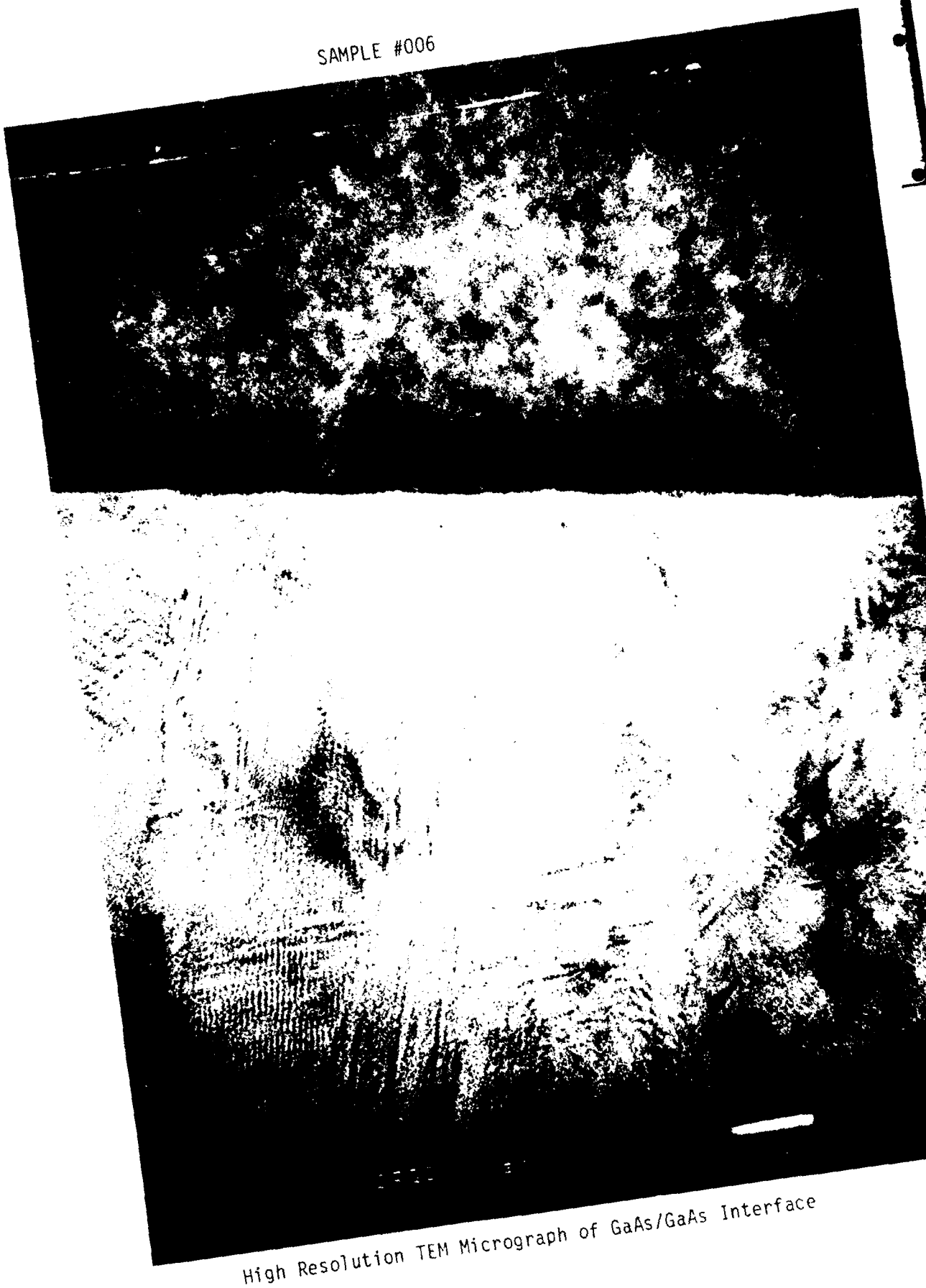
TEM Micrographs of Cross-Section



x80,000 x170,000

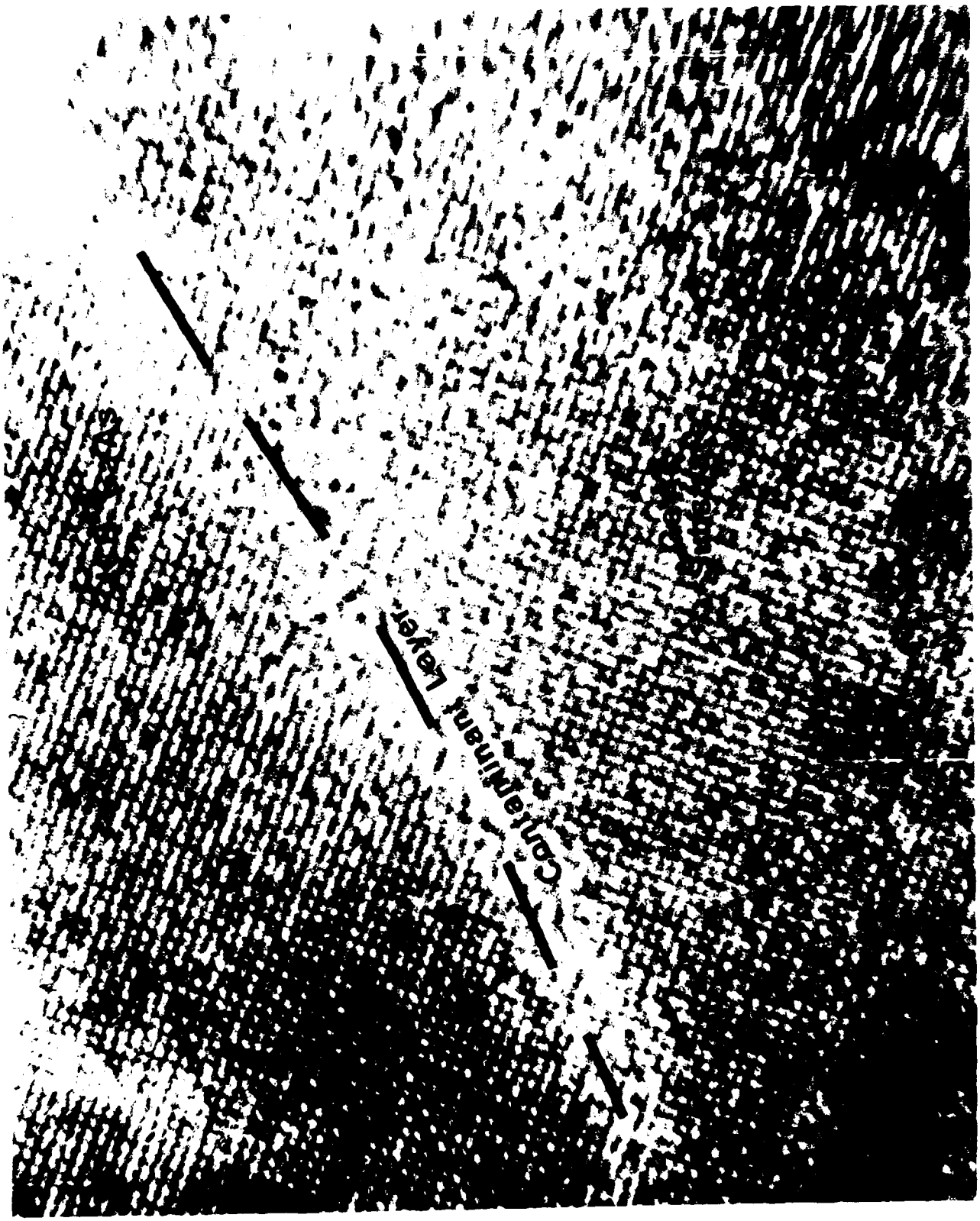
TEM Micrographs in Direction Normal to Surface

SAMPLE #006

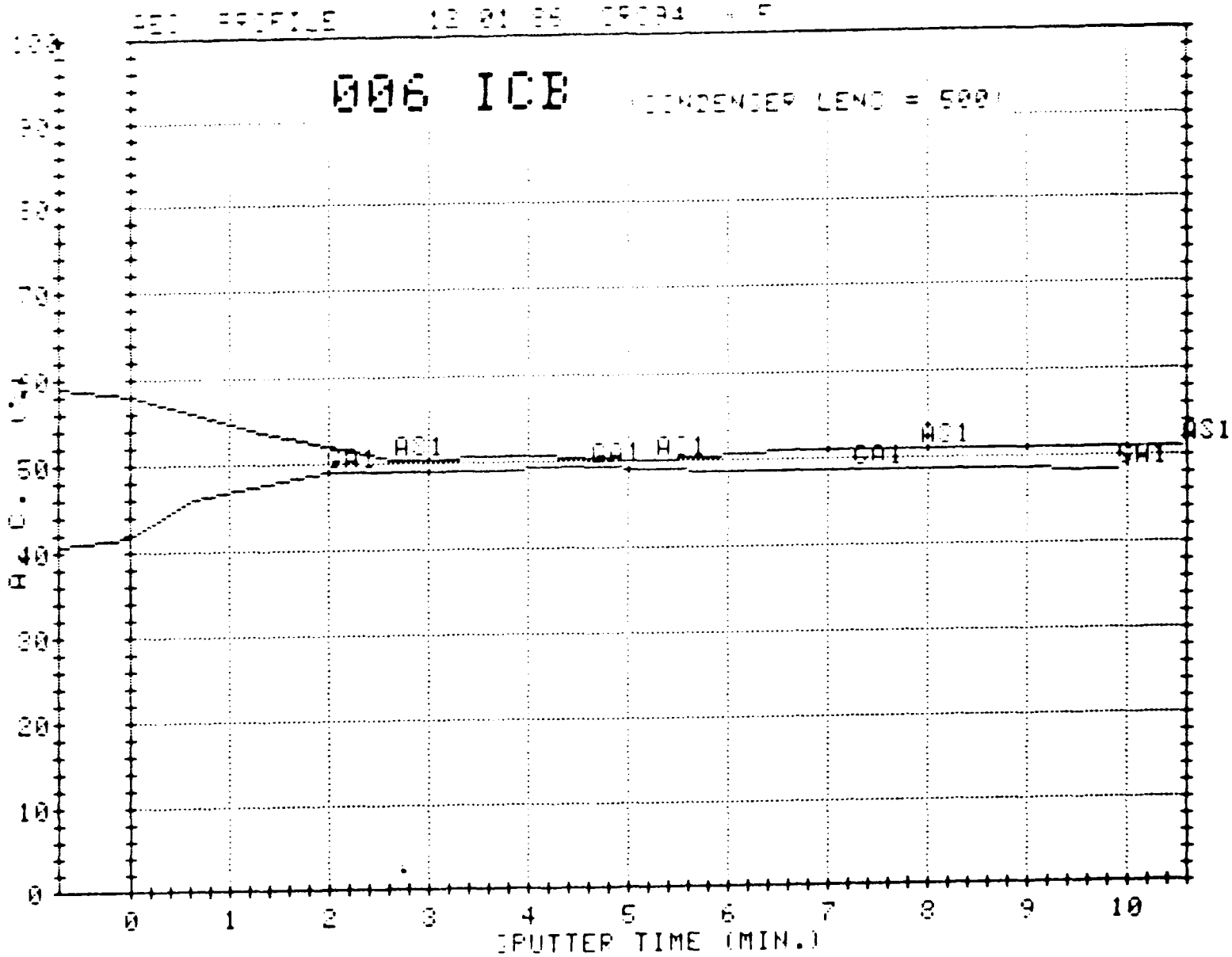


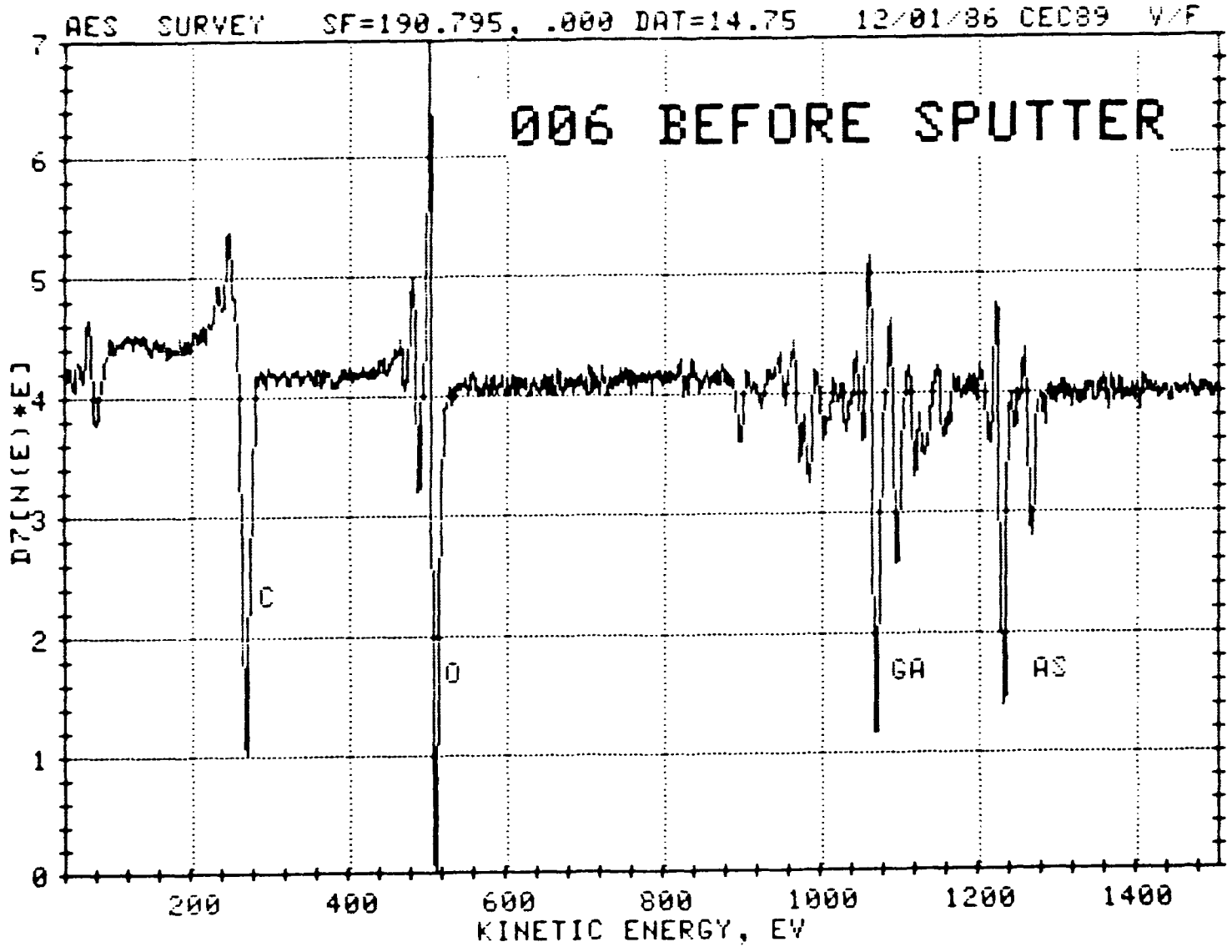
High Resolution TEM Micrograph of GaAs/GaAs Interface

SAMPLE #006



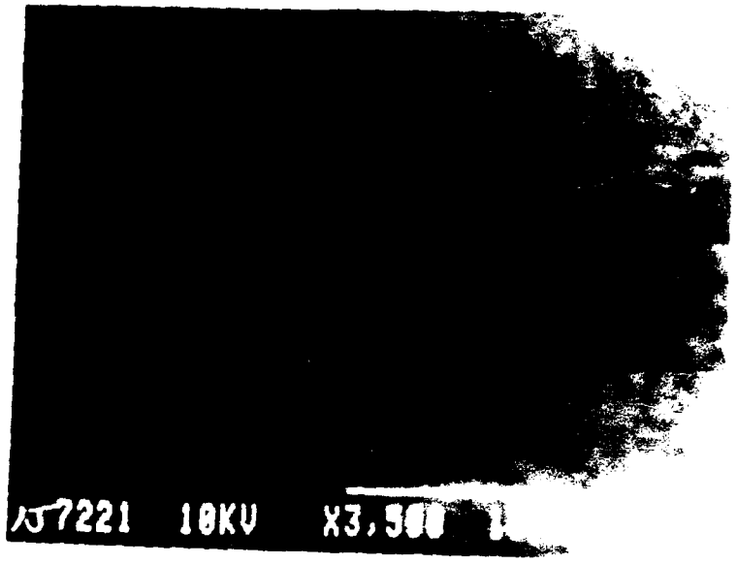
High Resolution TEM Micrograph of GaAs/GaAs Interface


006 ICB
AG1
CA1
SI1
ATOMIC %
SPUTTER TIME (MIN.)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
9
10

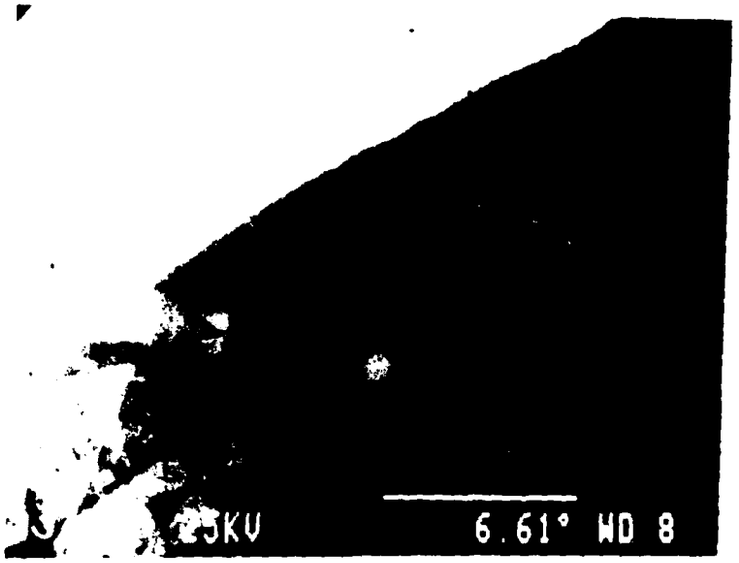

AES SURVEY SF=190.795, .000 DAT=14.75 12/01/86 CEC89 V/F
006 BEFORE SPUTTER
DZ[N](E)*E3
KINETIC ENERGY, EV
C
O
GA
AS
0
1
2
3
4
5
6
7
200
400
600
800
1000
1200
1400

RUN NO. 007

SAMPLE #007



SEM Micrograph of Film Surface

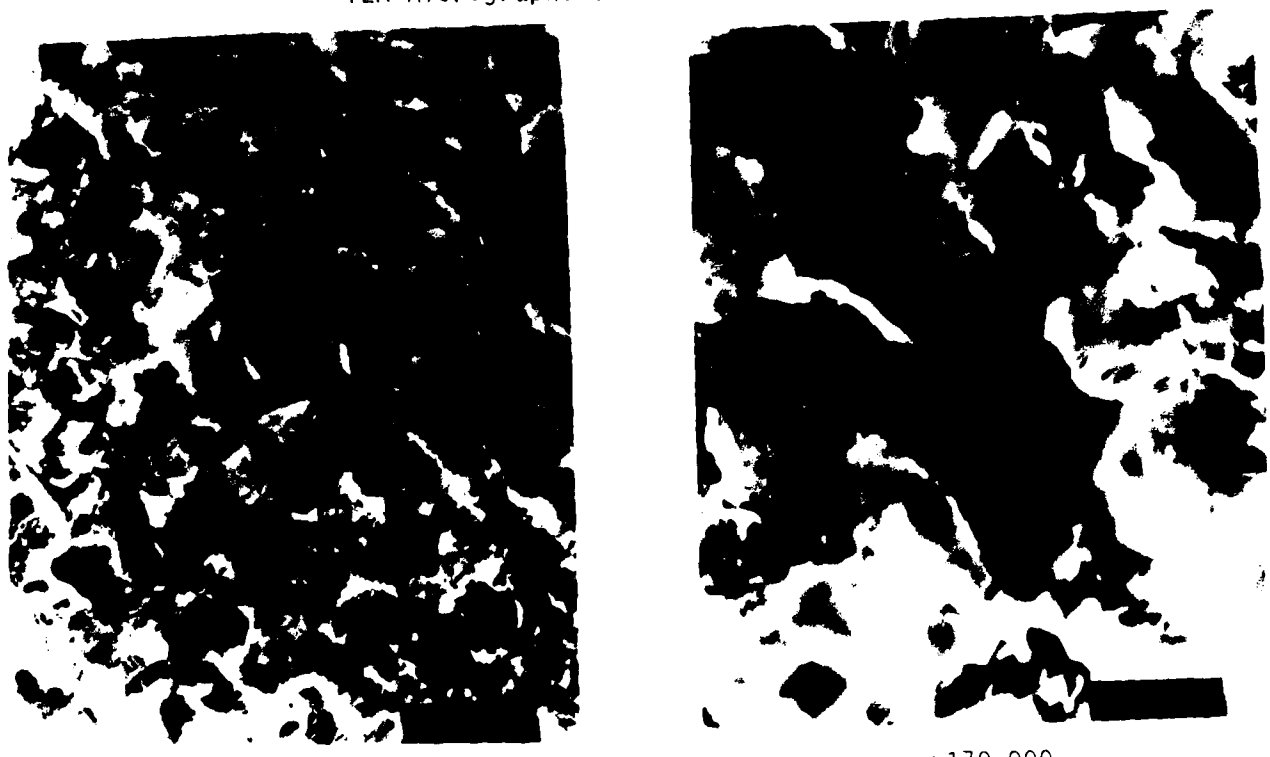


Electron channeling pattern taken near wafer edge. The sharp pattern emanates from the exposed substrate surface. The ICB film (top) does not yield a channeling pattern.

SAMPLE #007

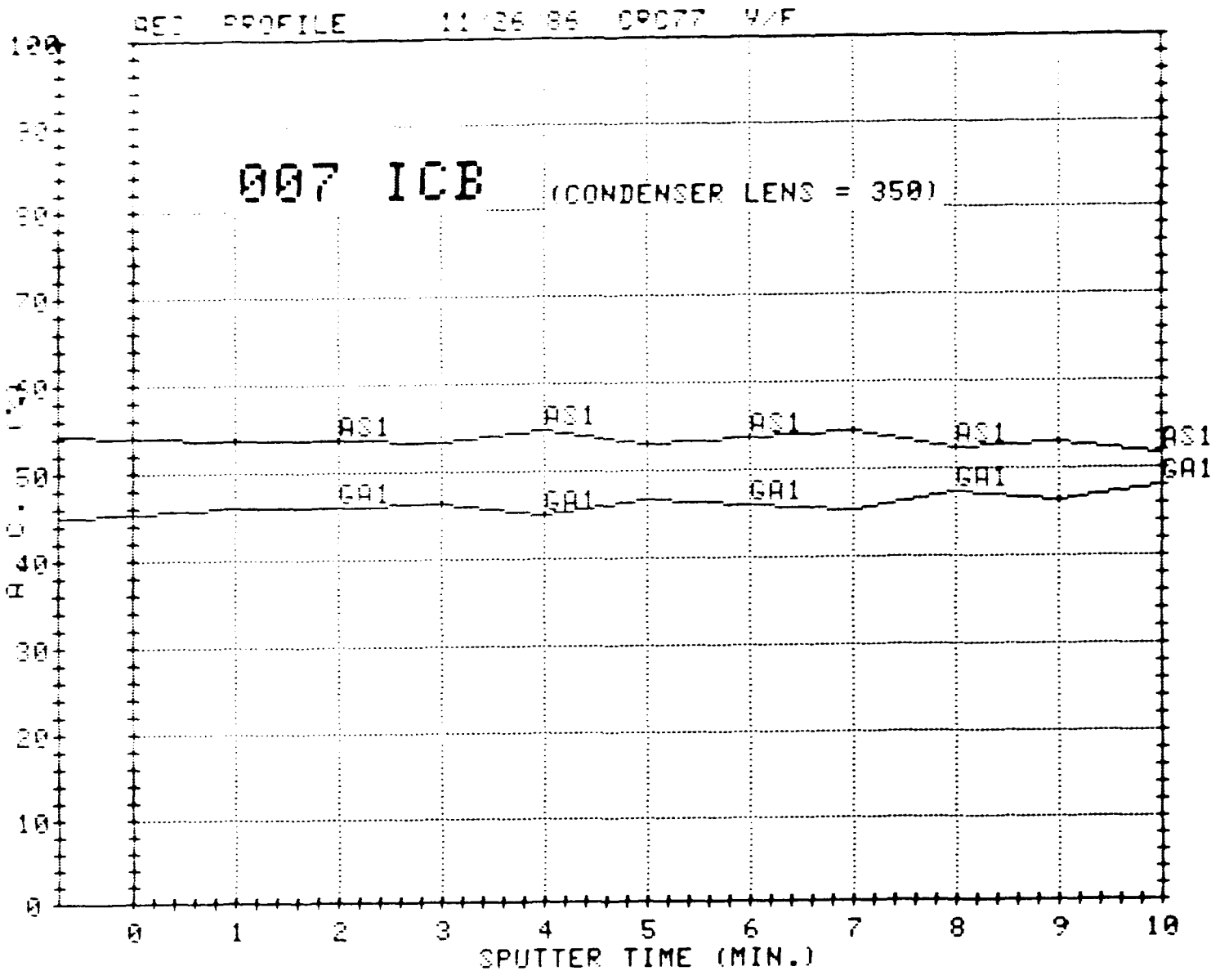
x22,000 x36,000

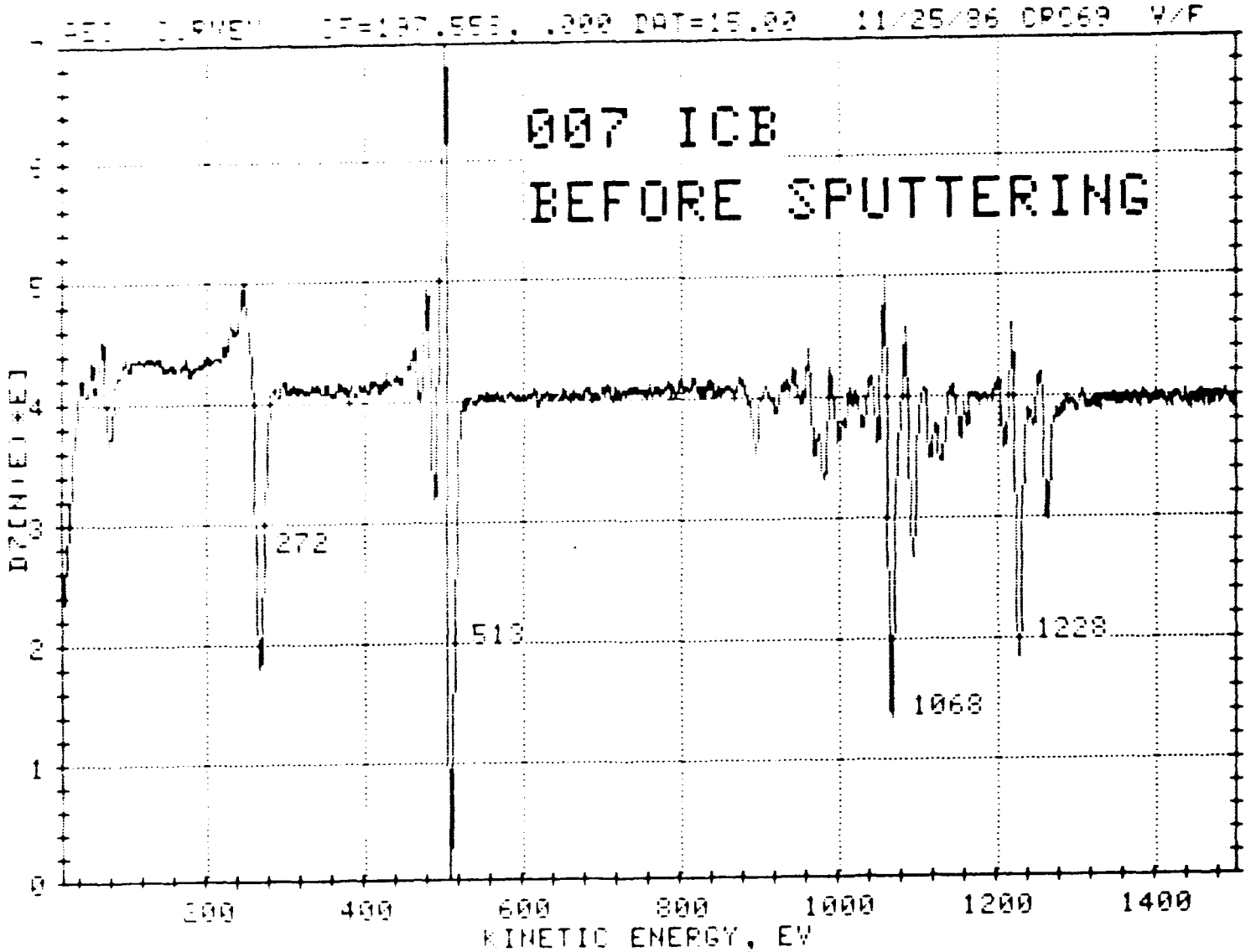
TEM Micrographs of Cross-Section



x80,000 x170,000

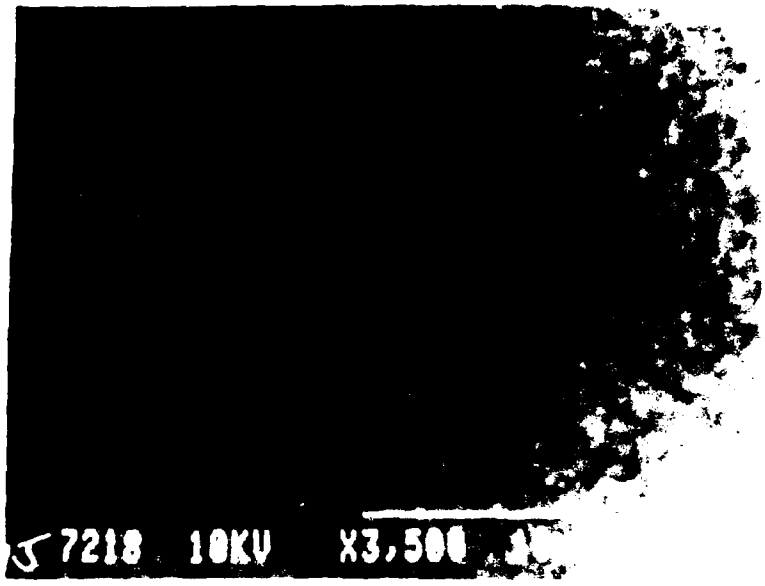
TEM Micrographs in Direction Normal to Surface


007 ICB
(CONDENSER LENS = 350)
AS1
GA1
SPUTTER TIME (MIN.)
0
1
2
3
4
5
6
7
8
9
10
10
20
30
40
50
70
90
100

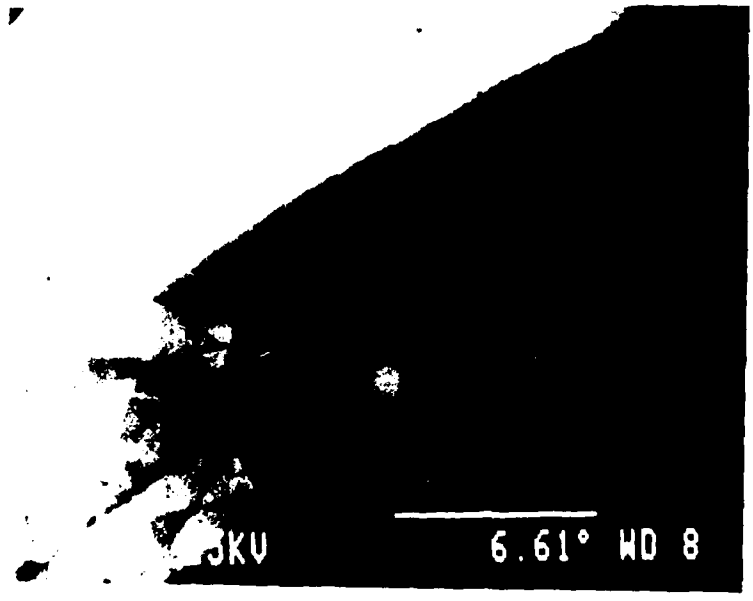

007 ICB
BEFORE SPUTTERING
272
513
1068
1228
DN(E)*E
KINETIC ENERGY, EV
0
1
2
3
4
5
200
400
600
800
1000
1200
1400

RUN NO. 008

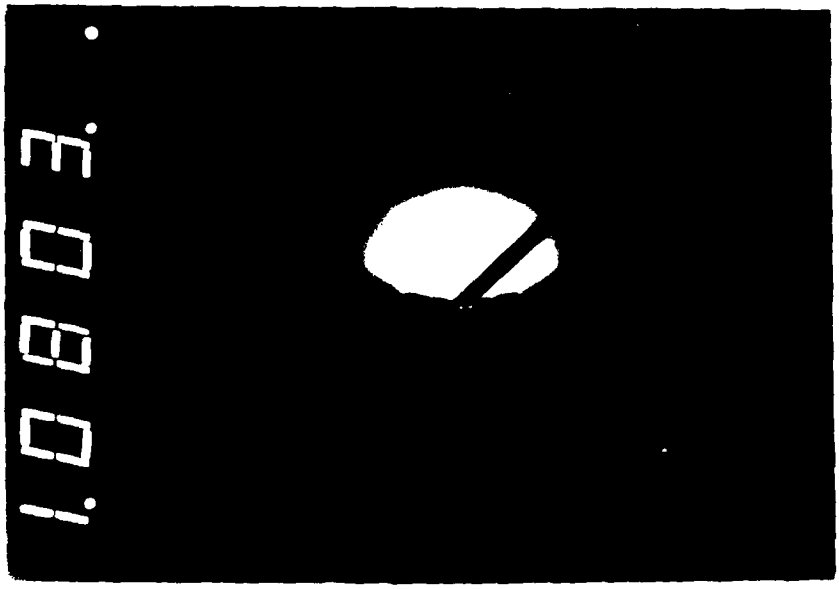
SAMPLE #008



SEM Micrograph of Film Surface

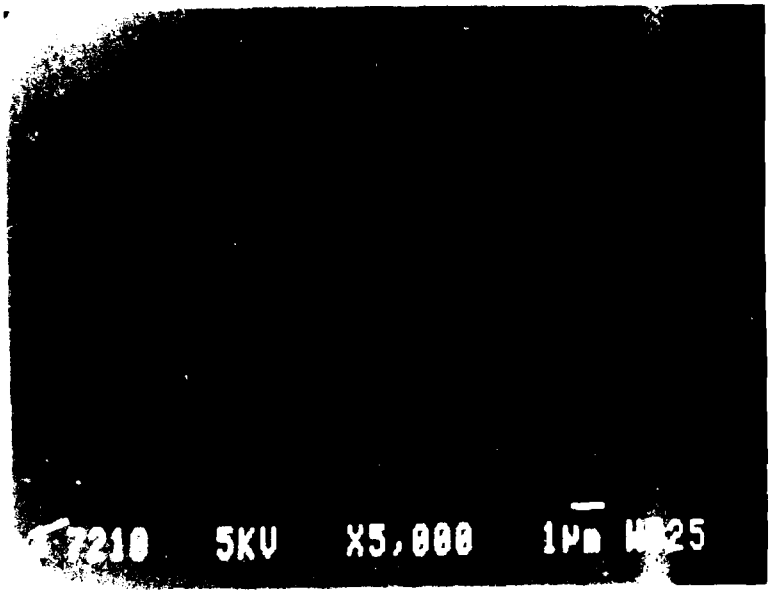


Electron channeling pattern taken near wafer edge. The sharp pattern emanates from the exposed substrate surface. The ICB film (top) does not yield a channeling pattern.



RHEED Pattern

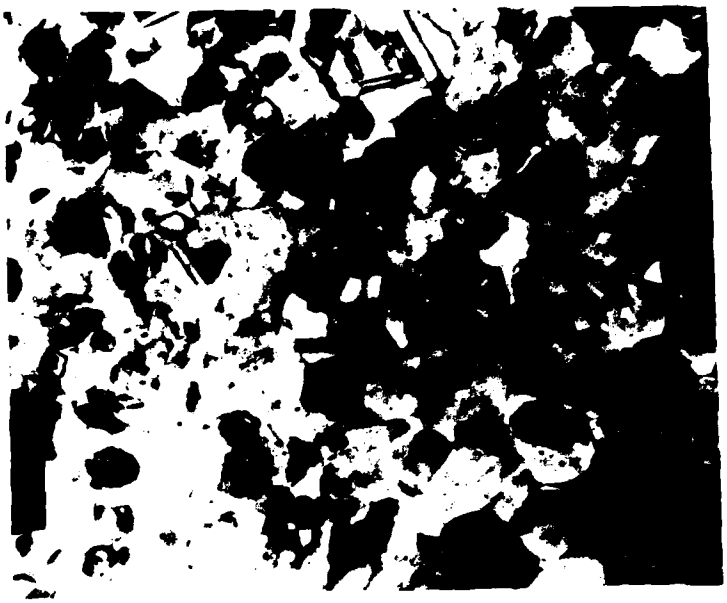
SAMPLE #008



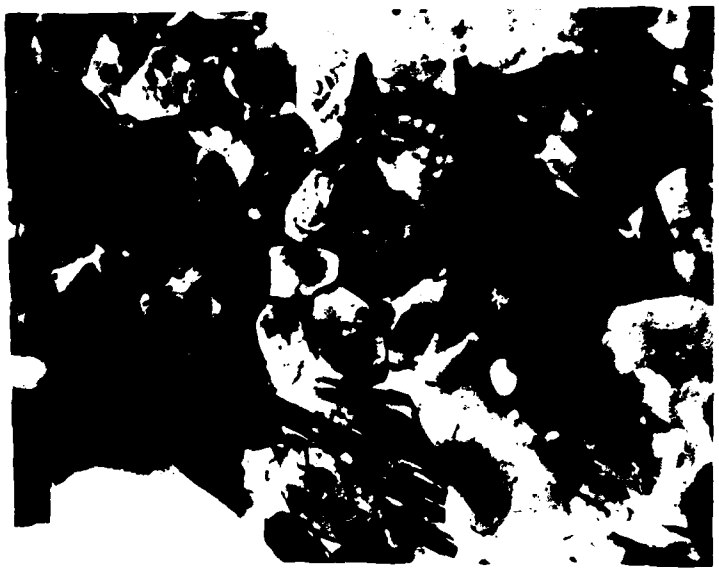
Cleave
Cross
Section

Film
Thickness
Approximately
1.0 µm

SAMPLE #008



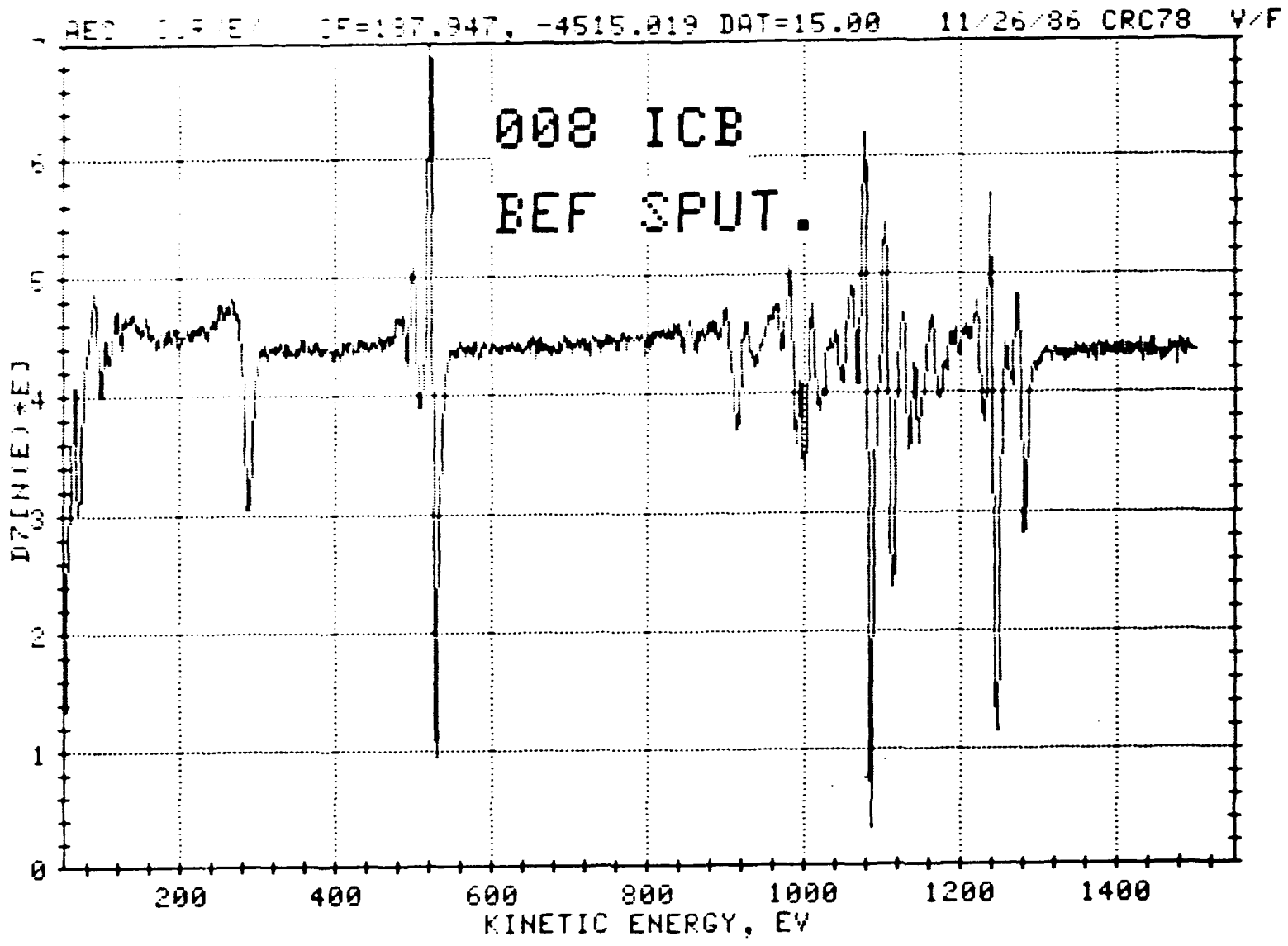
x36,000

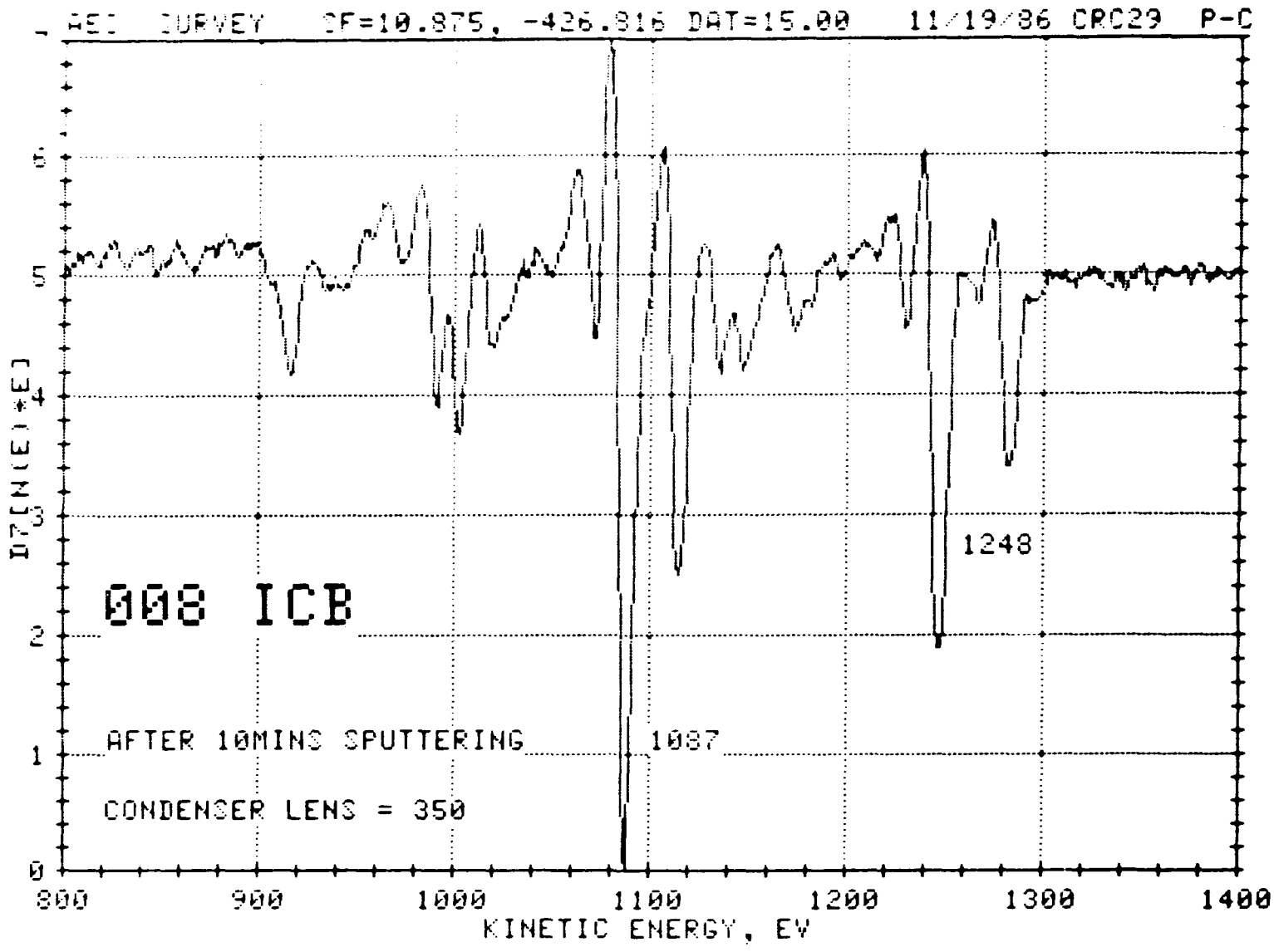


x36,000

x80,000

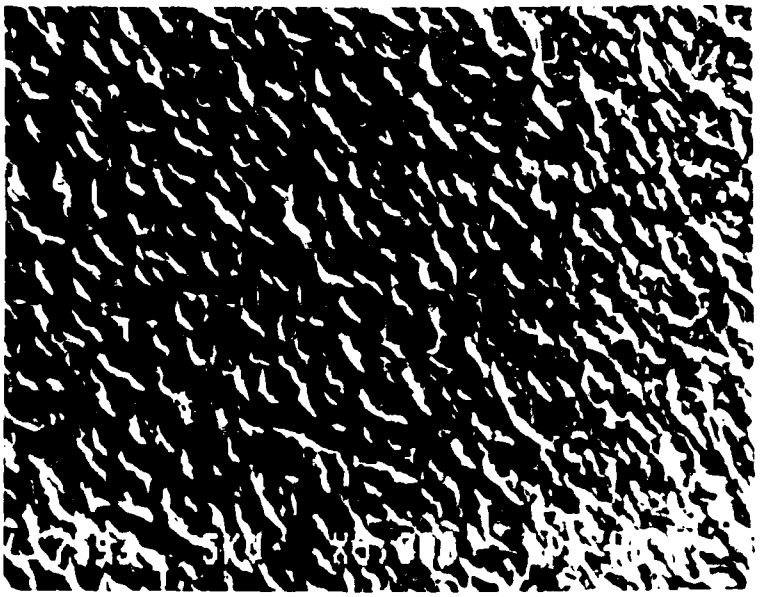
TEM Micrographs in Direction Normal to Surface


008 ICB
BEF SPUT.
D7[N(E)*E]
KINETIC ENERGY, EV
0
1
200
400
600
800
1000
1200
1400


AEI SURVEY CF=10.875, -426.816 DAT=15.00 11/19/86 CRC23 P-C
D?[N(E)*E]
0
1
2
3
4
5
6
800
900
1000
1100
1200
1300
1400
KINETIC ENERGY, EV
008 ICB
AFTER 10MINS SPUTTERING
CONDENSER LENS = 350
1087
1248

RUN NO. 010

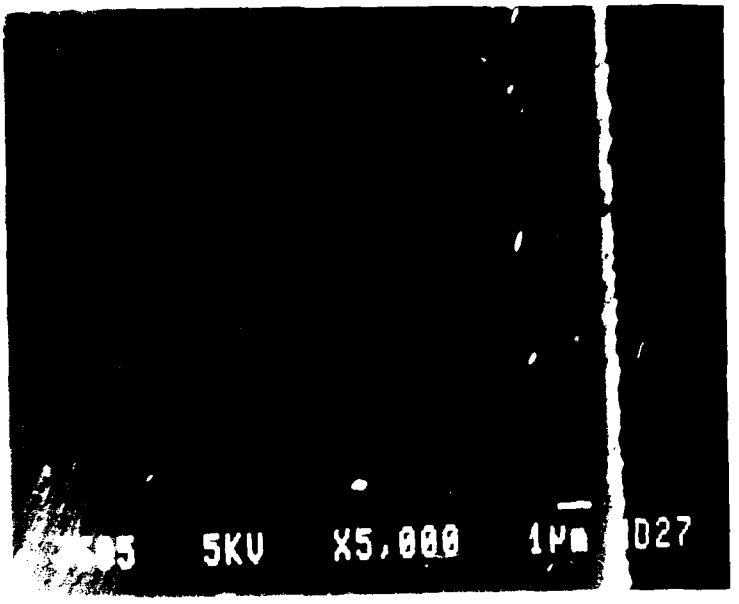
SAMPLE #010



SEM Micrograph of Film Surface

Electron Channeling Pattern from Film Surface

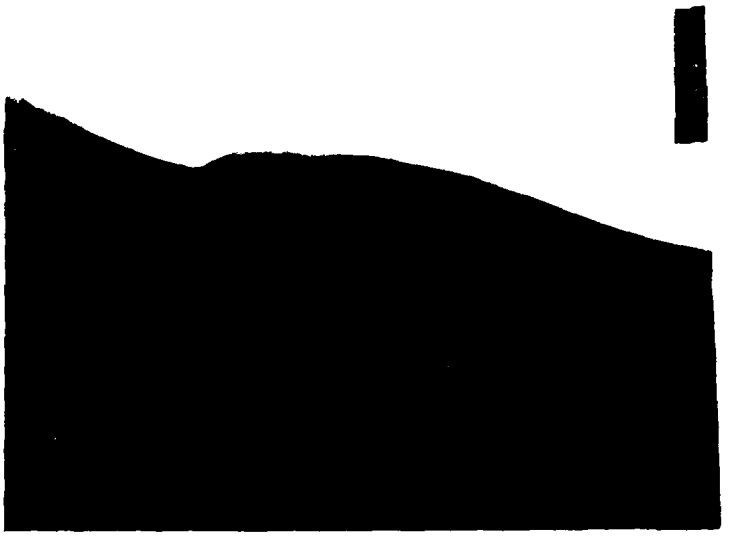
SAMPLE #010



Cleave
Cross
Section

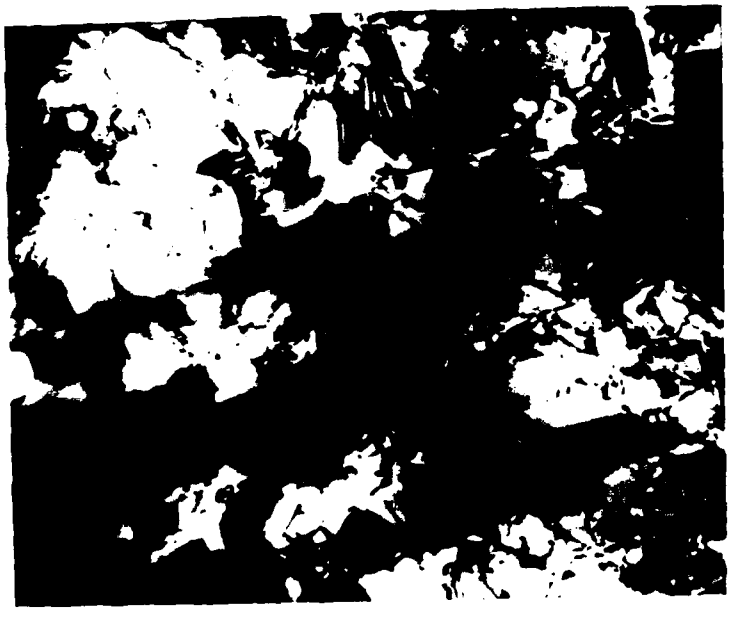
Film
Thickness
Approximately ?

SAMPLE #010



x30,000

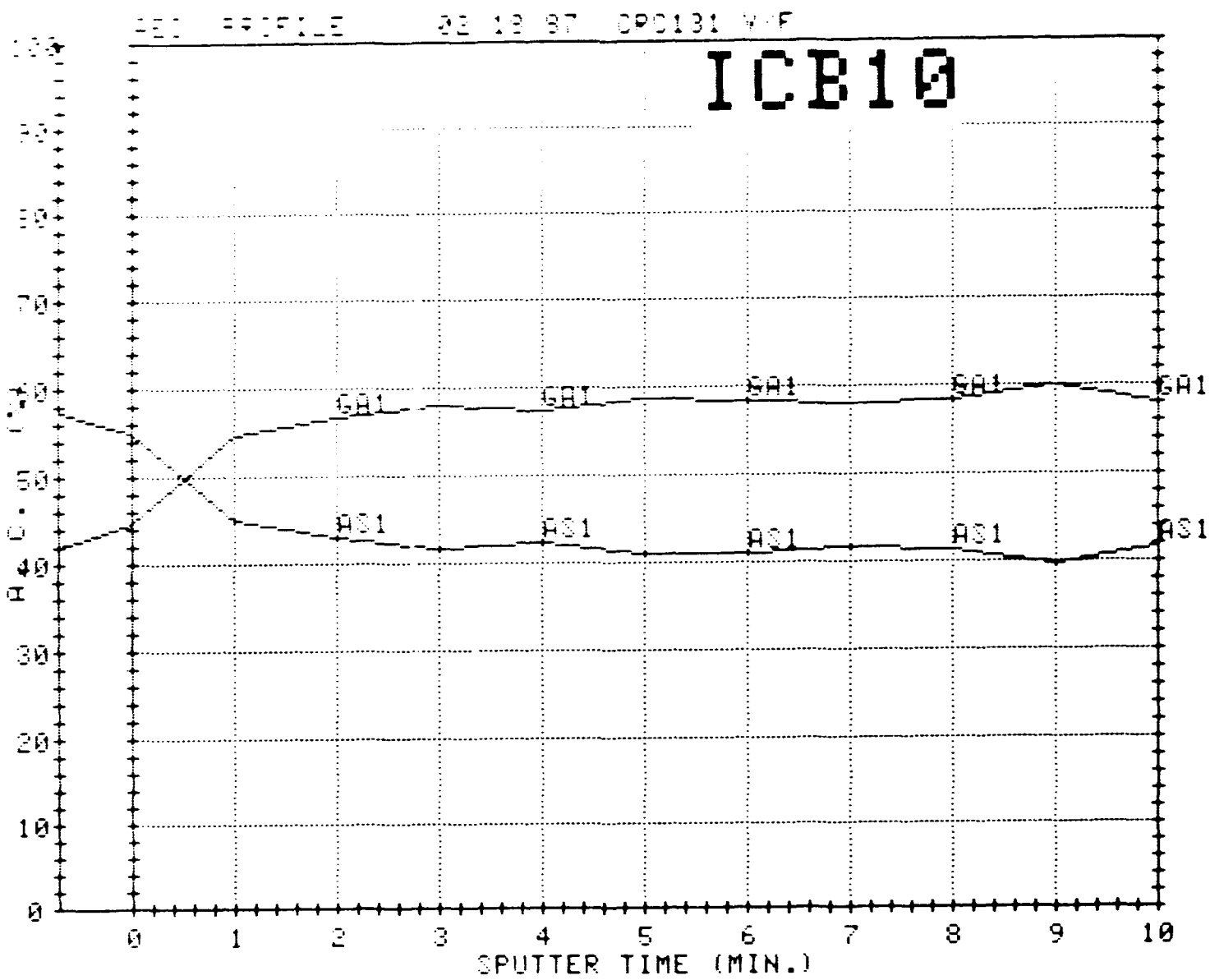
TEM Micrograph of Cross-Section

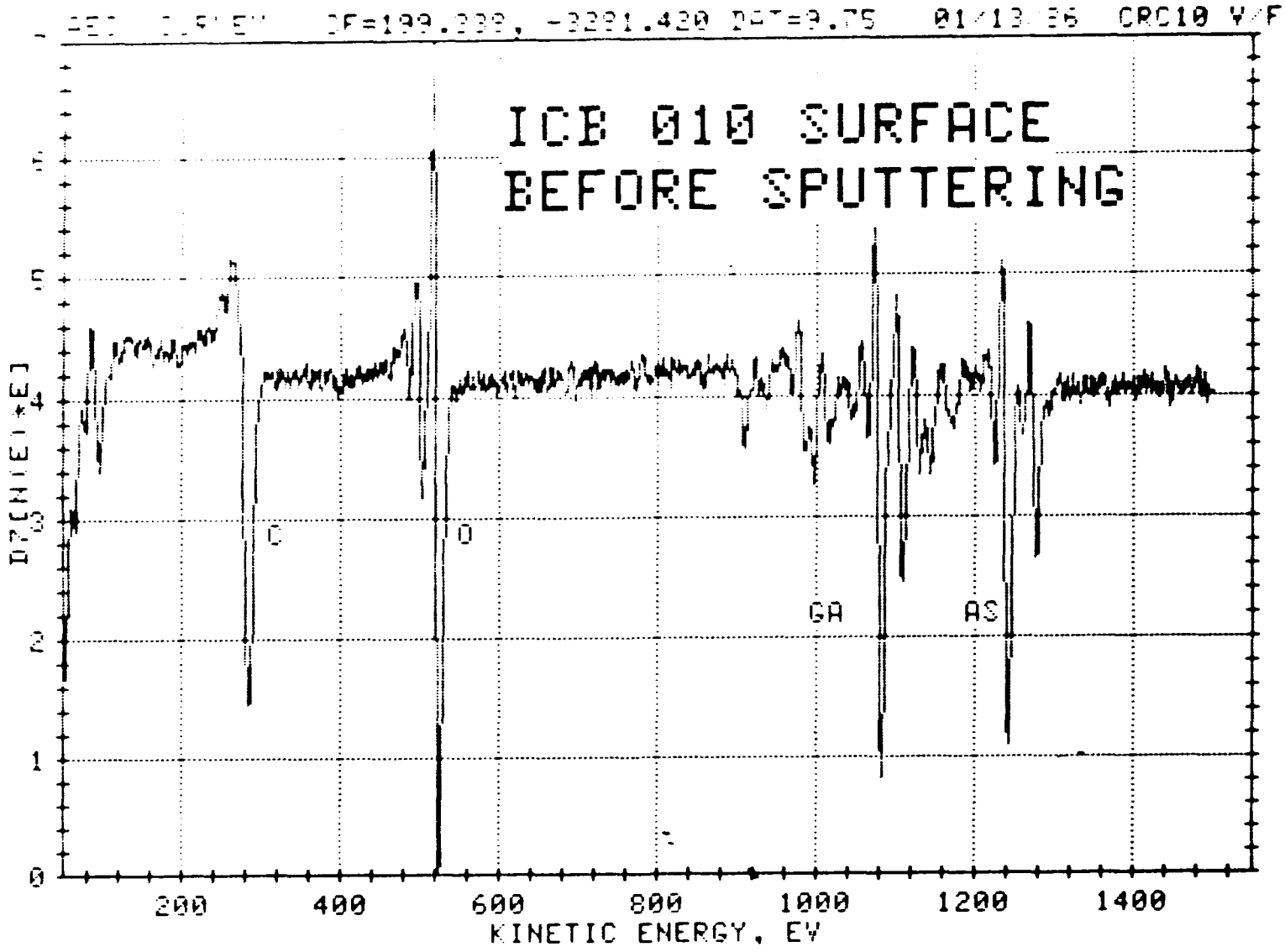


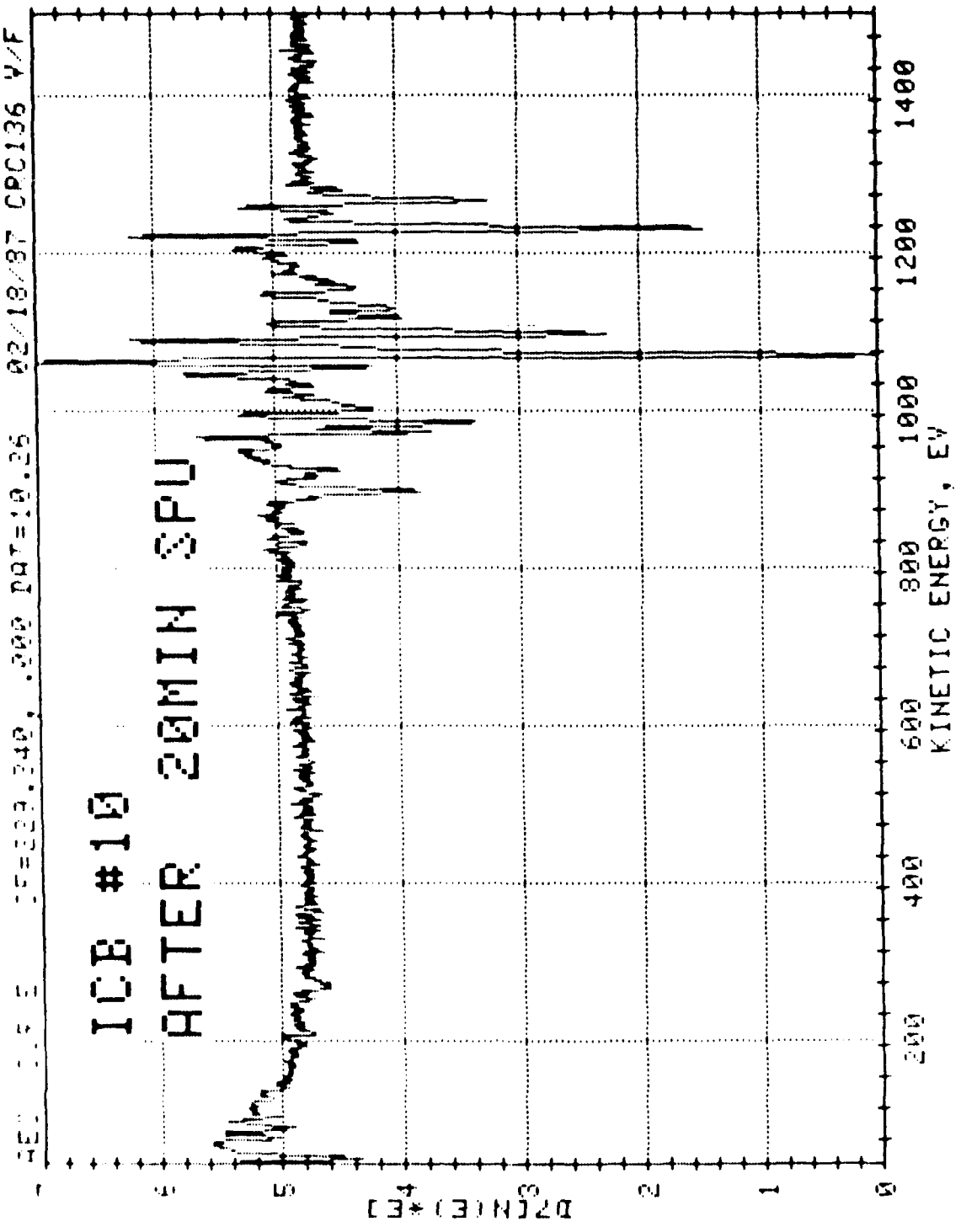
x36,000

x80,000

TEM Micrographs in Direction Normal to Surface

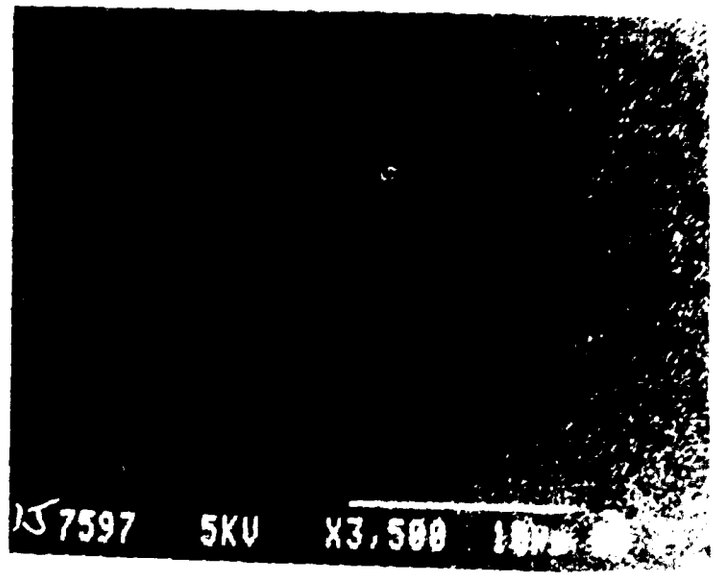

ICB10
GA1
AS1
SPUTTER TIME (MIN.)


ICB 010 SURFACE
BEFORE SPUTTERING
C
O
GA
AS
D?[N(E)*E]
KINETIC ENERGY, EV
0
1
2
3
4
5
200
400
600
800
1000
1200
1400

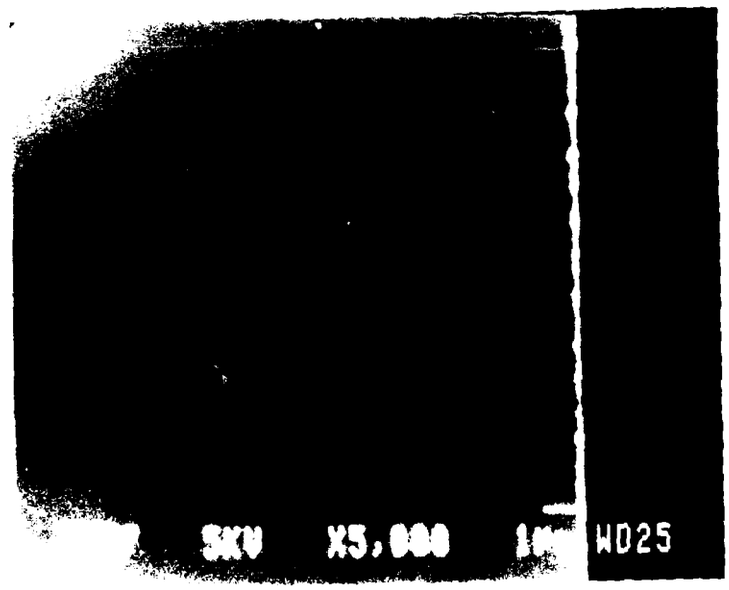

ICE #10
AFTER 20MIN SPU
02/18/87 CPC136 V/F
KINETIC ENERGY, EV
0
1
2
3
4
5
200
400
600
800
1000
1200
1400

RUN NO. 011

SAMPLE #011



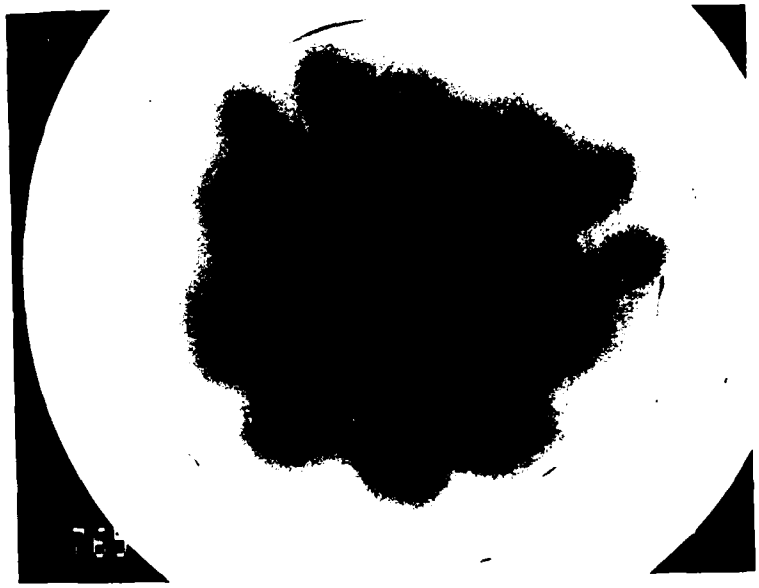
Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

SAMPLE #011



ECP
(Film)

SAMPLE #011

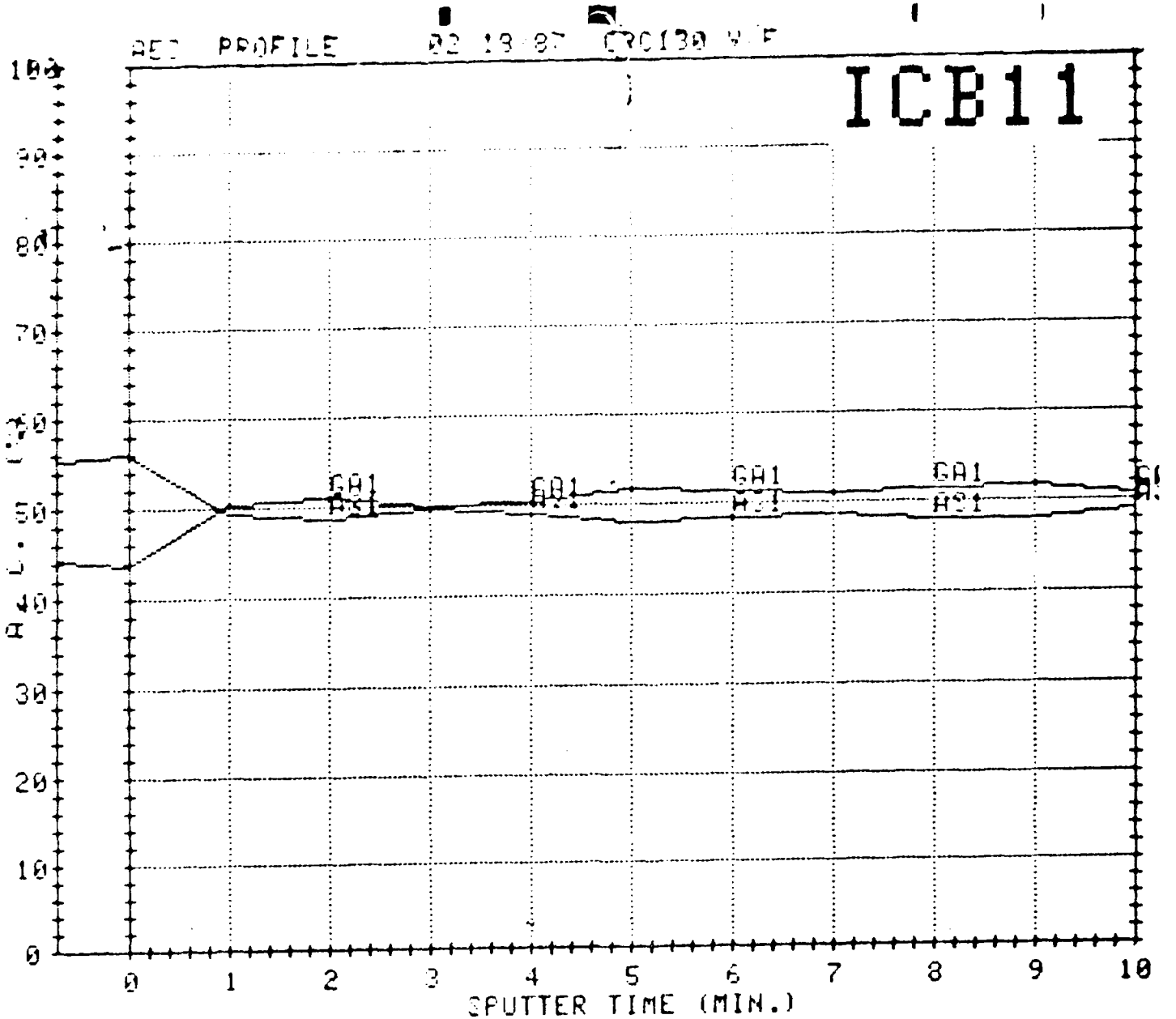
x130,000

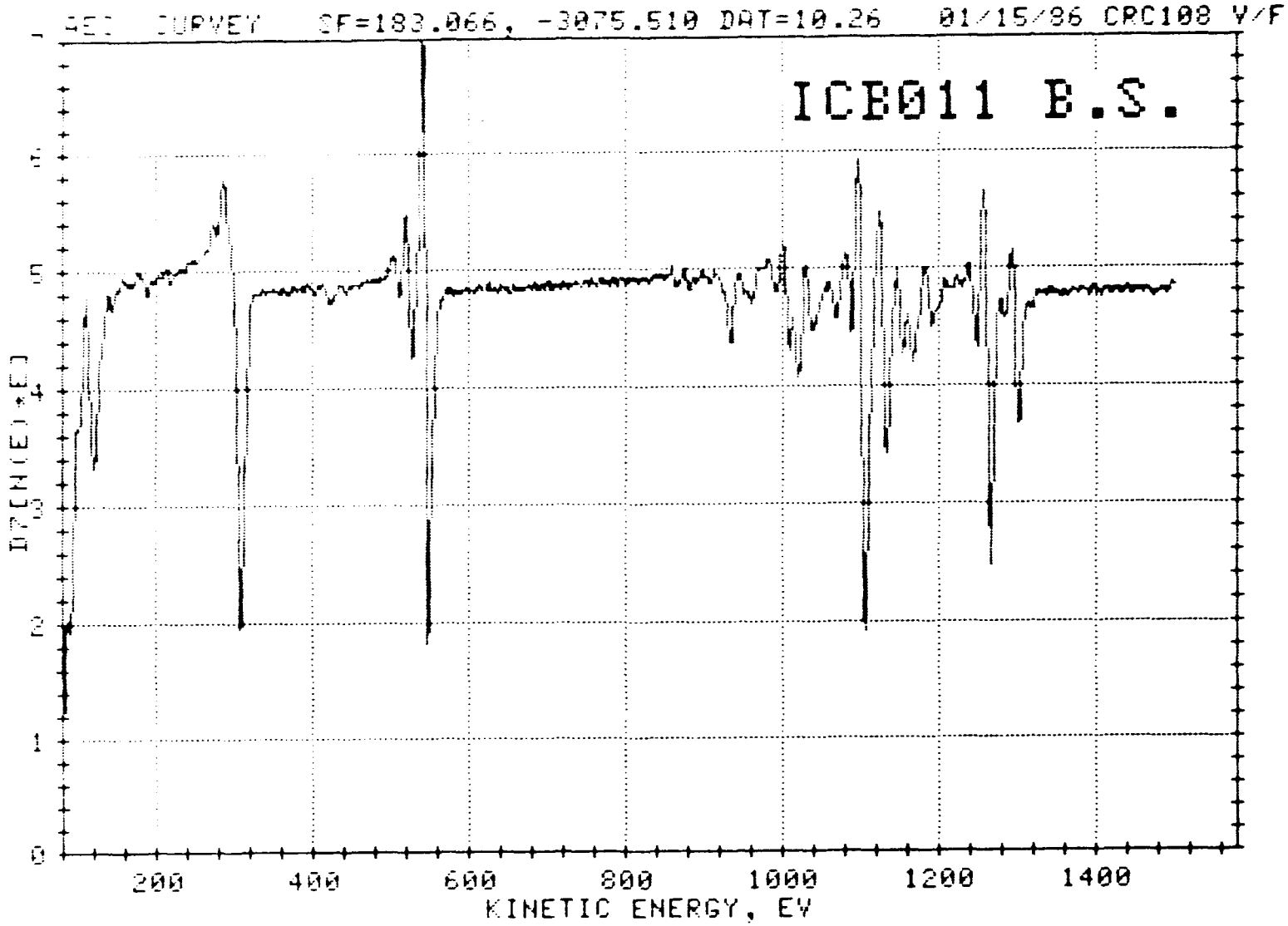
TEM Micrograph of Cross-Section

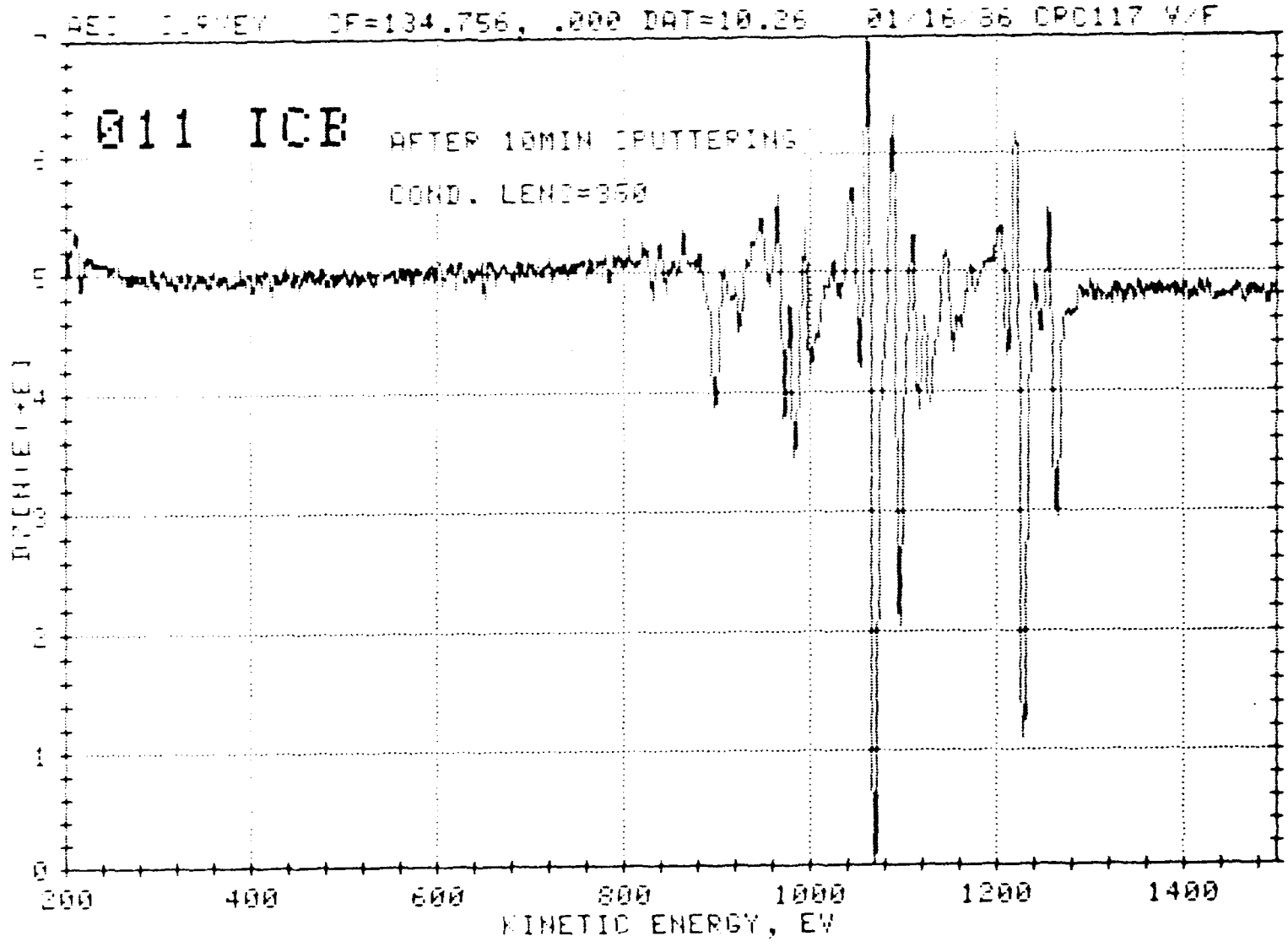
x36,000

x80,000

TEM Micrographs in Direction Normal to Surface


AES PROFILE 02 13 87 CRC130 W F
ICB11
100
90
80
70
60
50
40
30
20
10
0
ATOMIC %
GA1
AS1
GA1
AS1
GA1
AS1
GA1
AS1
0
1
2
3
4
5
6
7
8
9
10
SPUTTER TIME (MIN.)

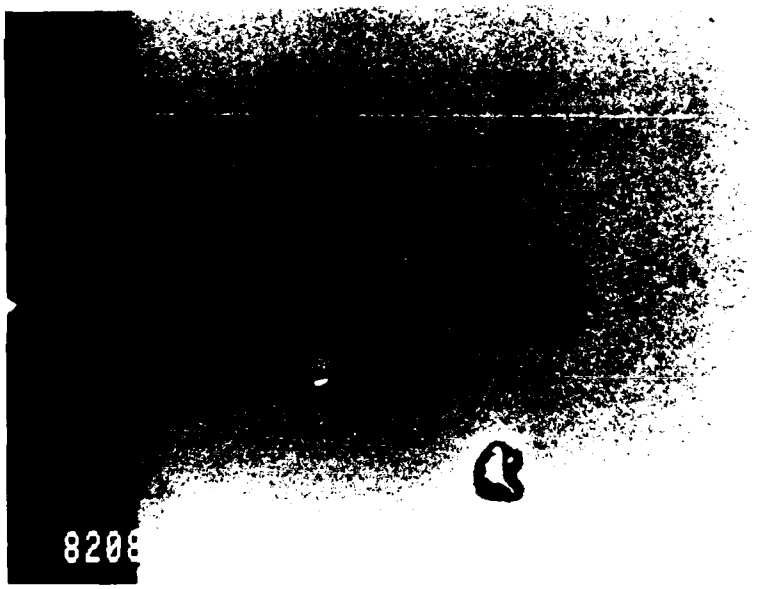

SEI SURVEY SF=183.066, -3075.510 DAT=10.26 01/15/86 CRC108 V/F
ICB011 B.S.
DP[N(E)*E]
0
1
2
3
4
5
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV


AEI 1.9KEV DF=134.756, .000 DAT=10.26 01/16/86 CRC117 V/F
011 ICB
AFTER 10MIN SPUTTERING
COND. LENG=350
DIFFERENTIAL
0
1
2
3
4
5
6
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 012

SAMPLE #012

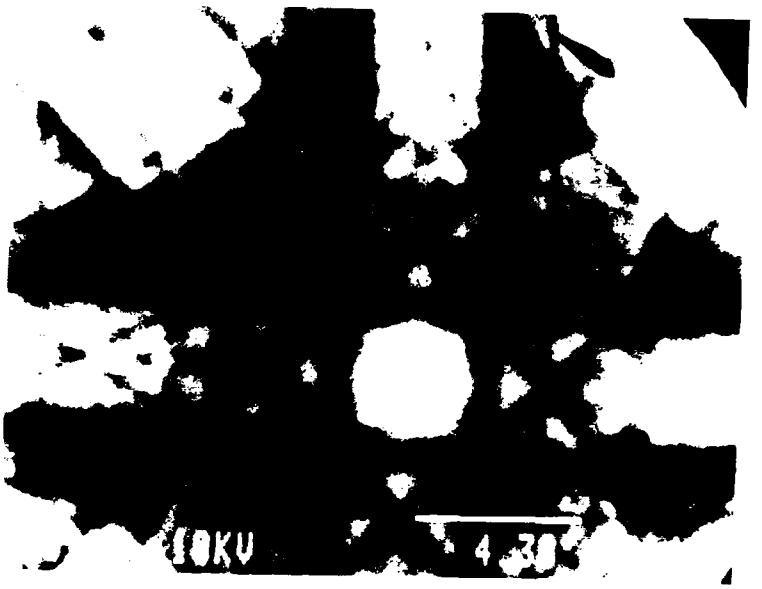
Film
Surface



Cleave
Cross
Section

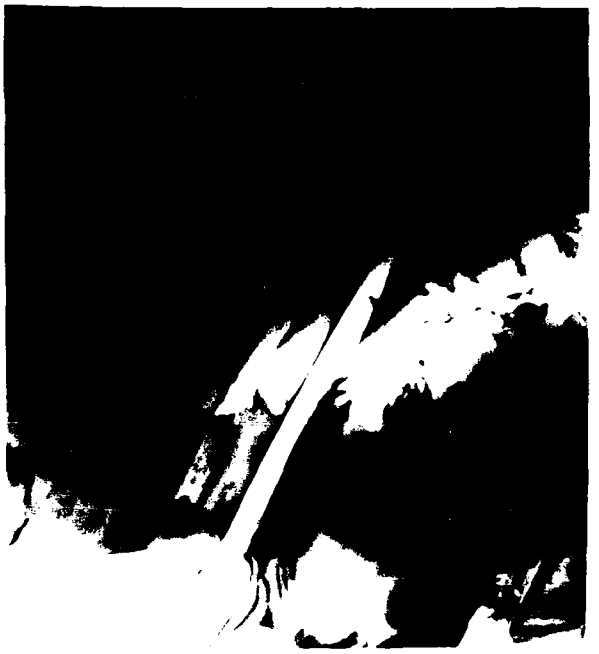
Film
Thickness
Approximately ?

SAMPLE #012



ECP
(Film)

SAMPLE #012



x36,000

TEM Micrographs in Direction Normal to Surface

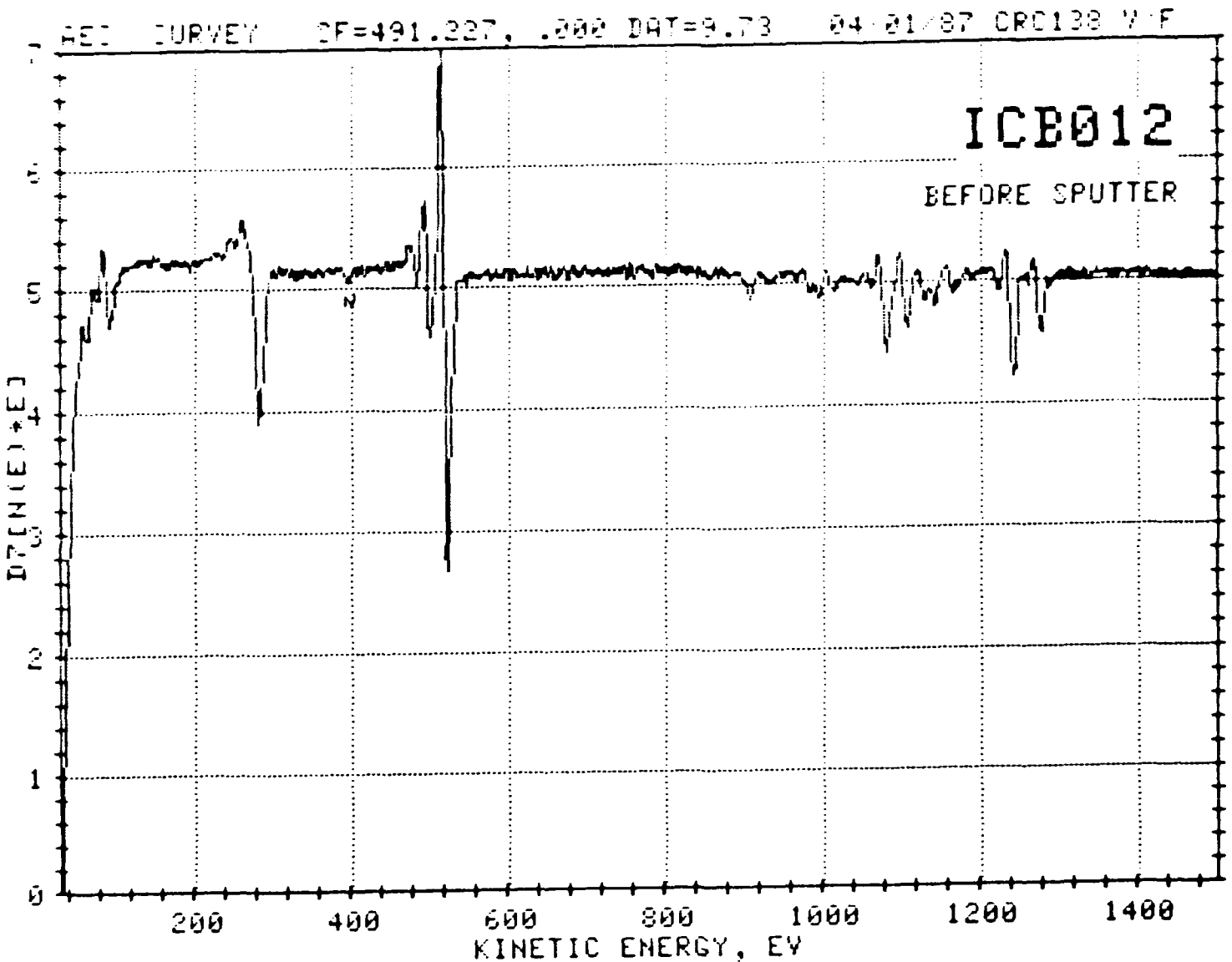
x36,000

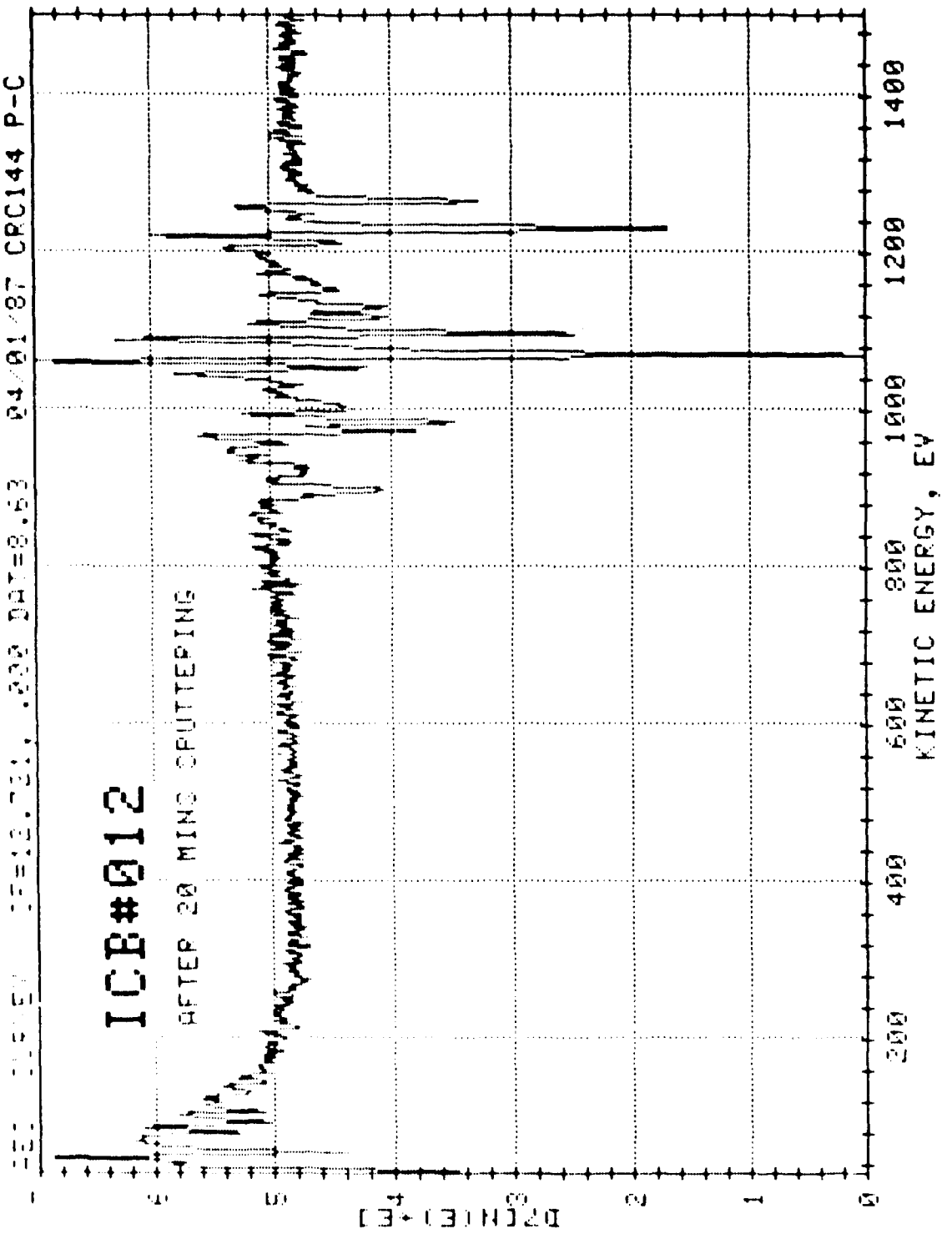
SAMPLE #012

x13,000

x46,000

x60,000

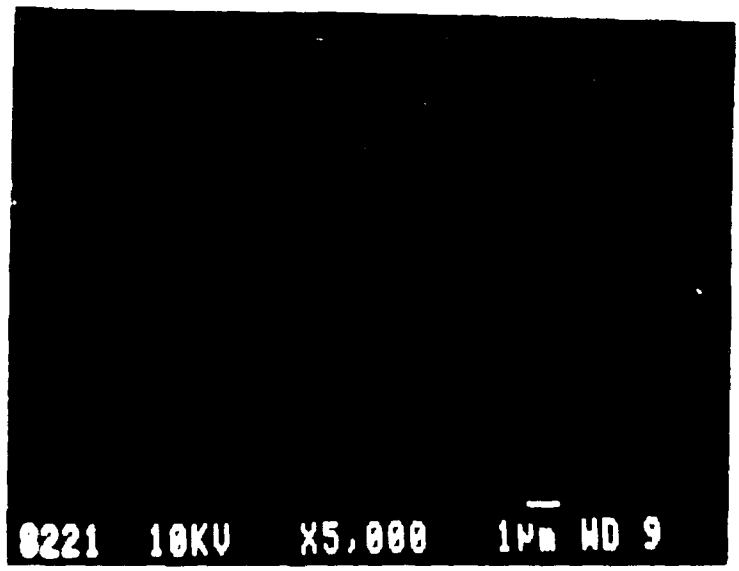

AEI SURVEY CF=491.227, .000 DAT=9.73 04-01-87 CRC138 V-F
ICB012
BEFORE SPUTTER
DZ(N(E)*E)
0
1
2
3
4
5
6
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV


ICB#012
AFTER 20 MINS SPUTTERING
04/01/87 CRC144 P-C
DCN(E)*E
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1

RUN NO. 013

SAMPLE #013

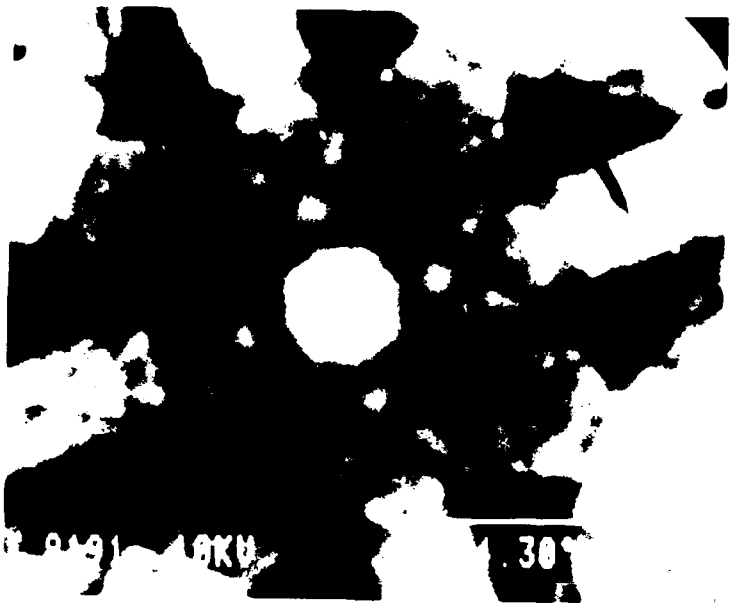
Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

SAMPLE #013



ECP
(Film)

SAMPLE #013

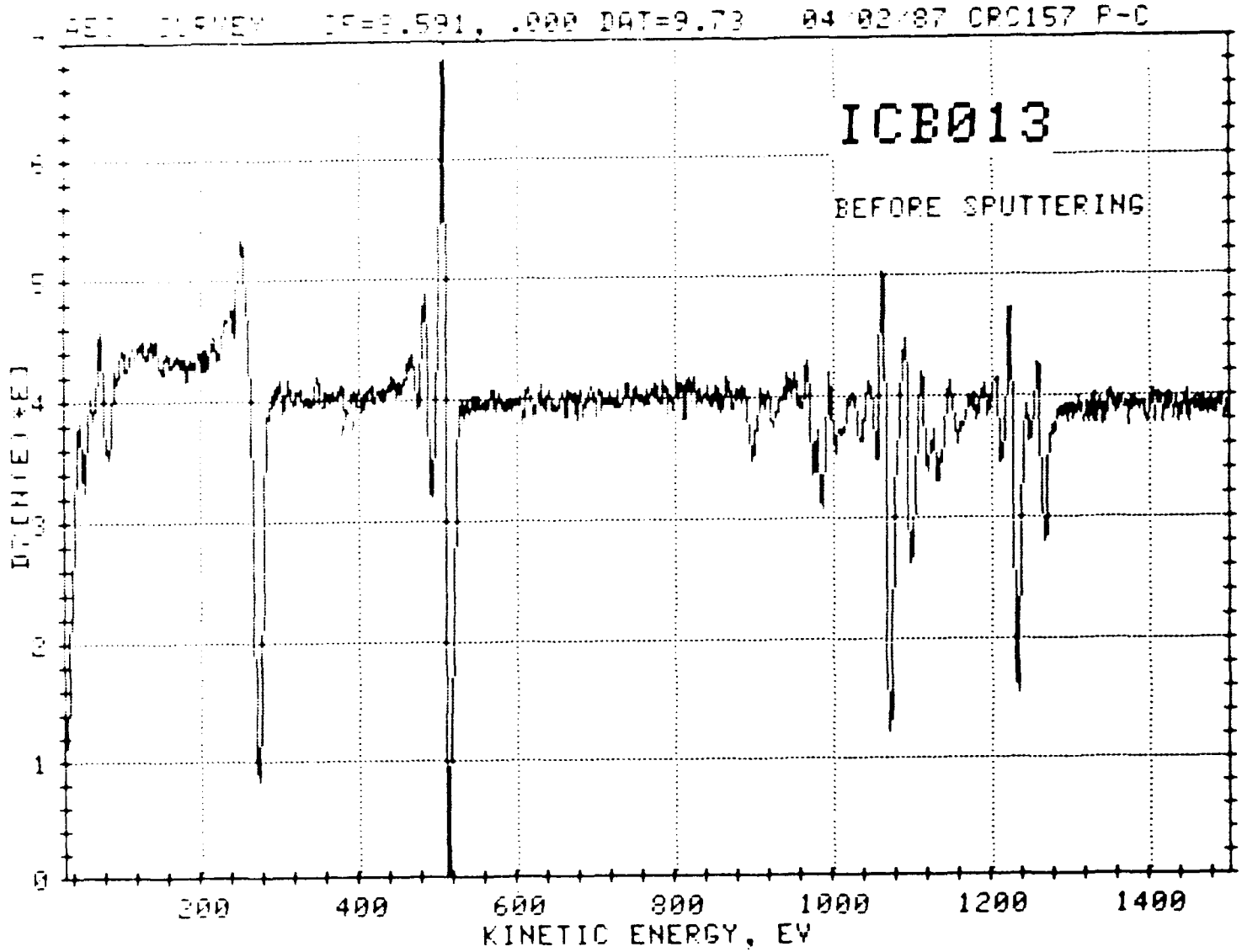
x28,000

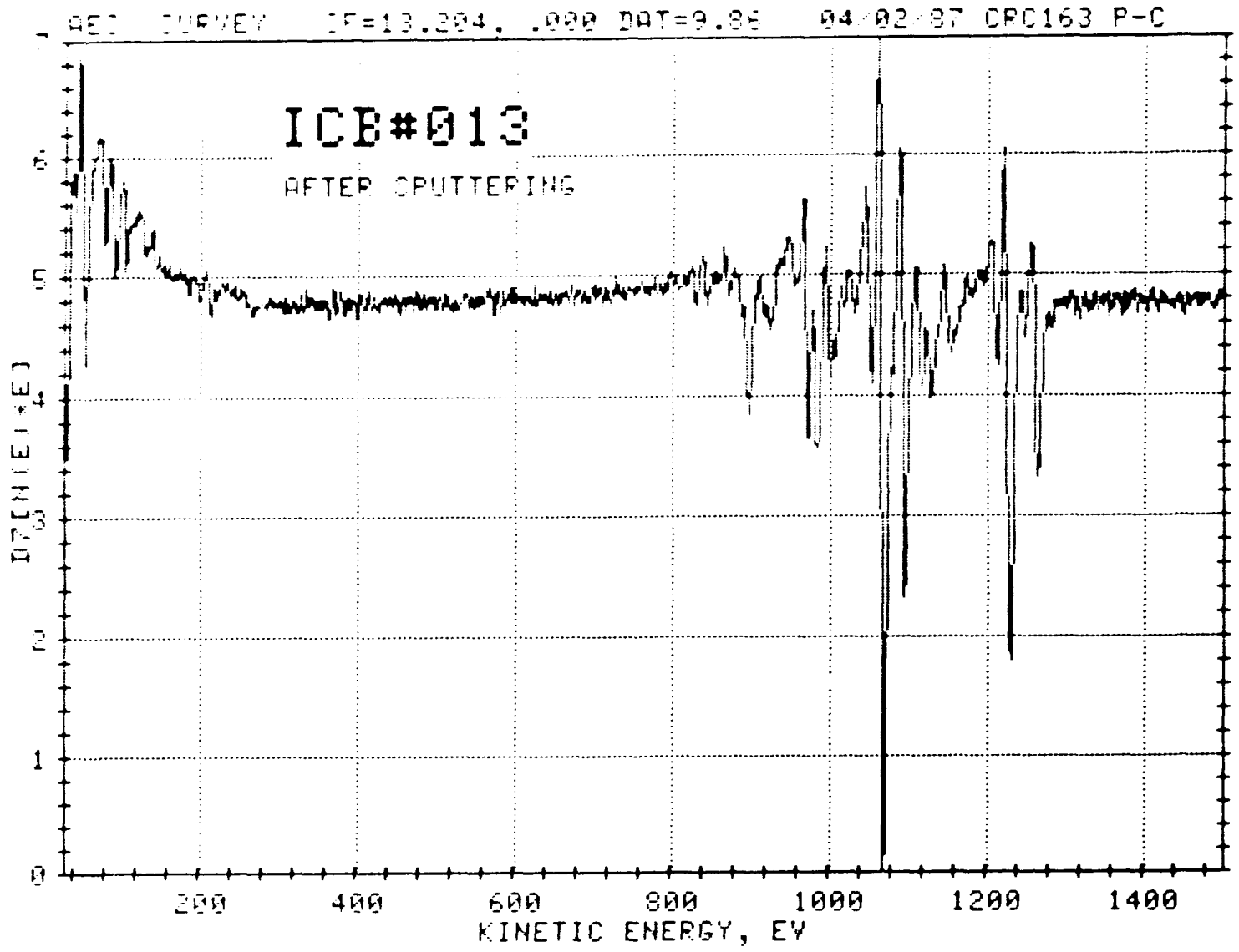
TEM Micrograph of Cross-Section

x36,000

x80,000

TEM Micrographs in Direction Normal to Surface


ICB013
BEFORE SPUTTERING
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
4
5


AES SURVEY EF=13.284, .000 DAT=9.85 04/02/87 CRC163 P-C
ICB#013
AFTER SPUTTERING
D7(N(E)*E)
0
1
2
3
4
5
6
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 014

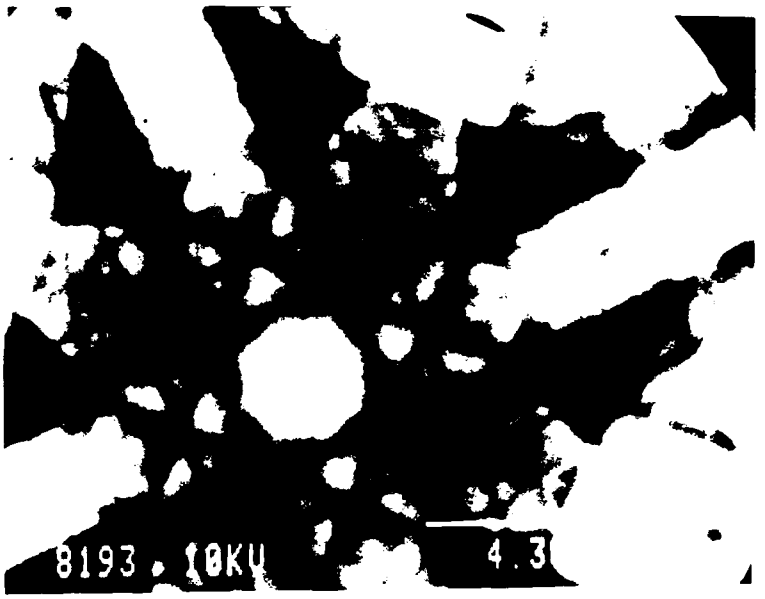
SAMPLE #014

Film
Surface

Cleave
Cross
Section

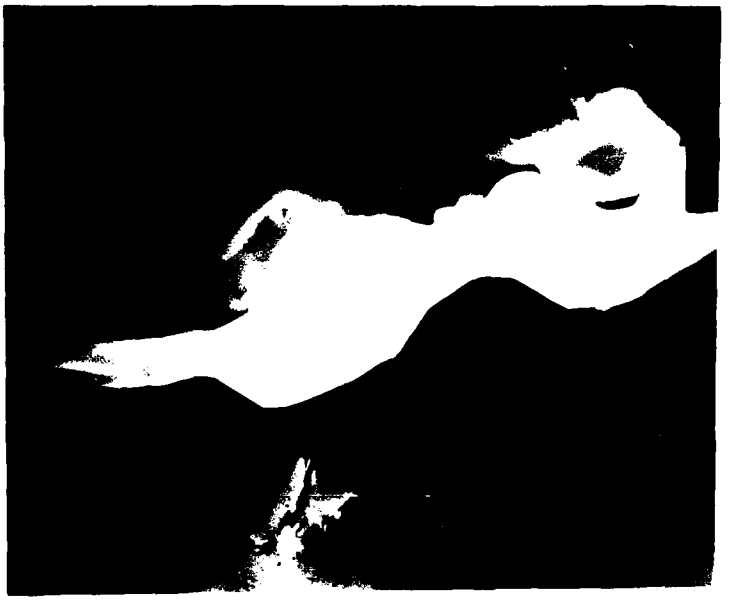
Film
Thickness
Approximately ?

SAMPLE #014



ECP
(Film)

SAMPLE #014



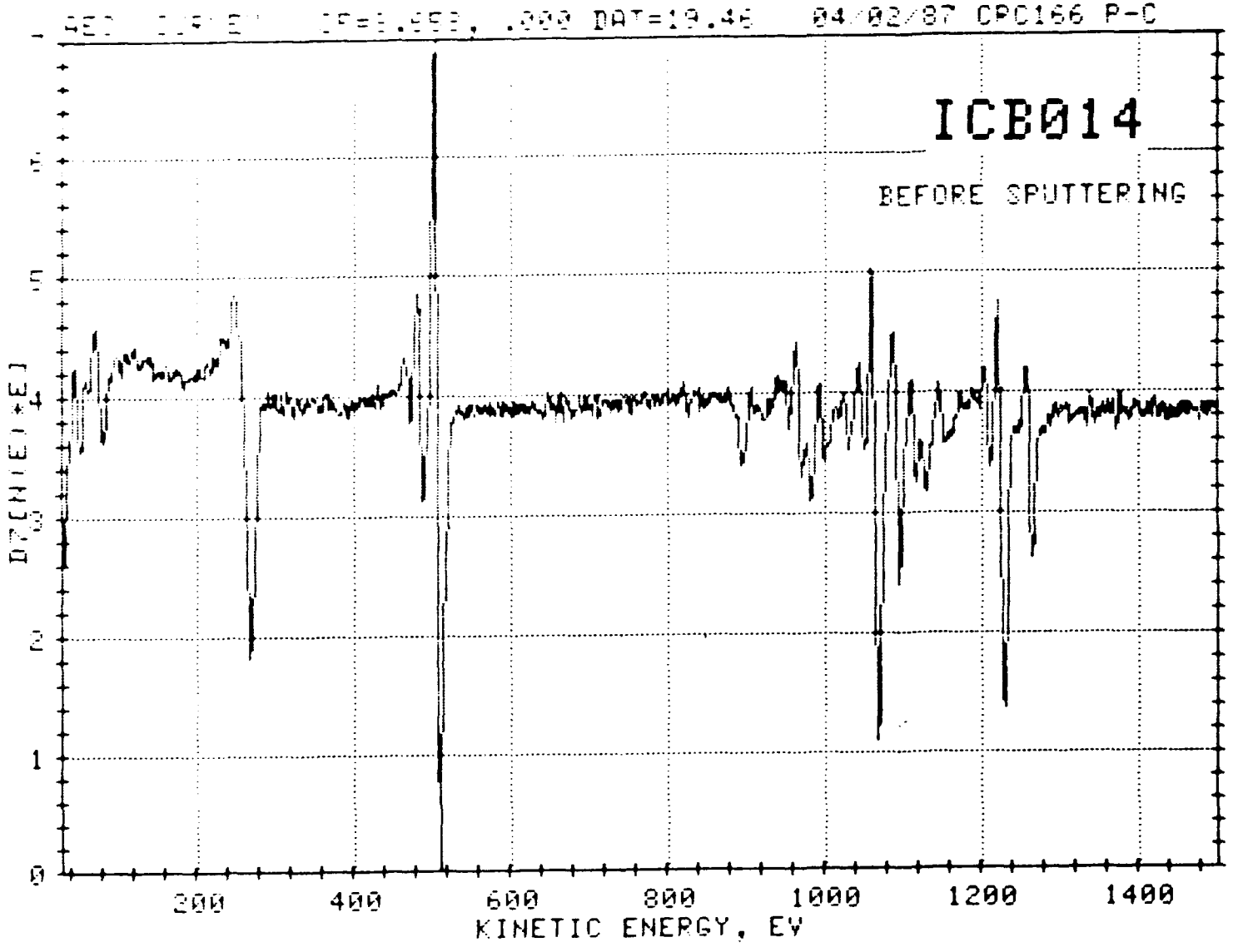
x36,000

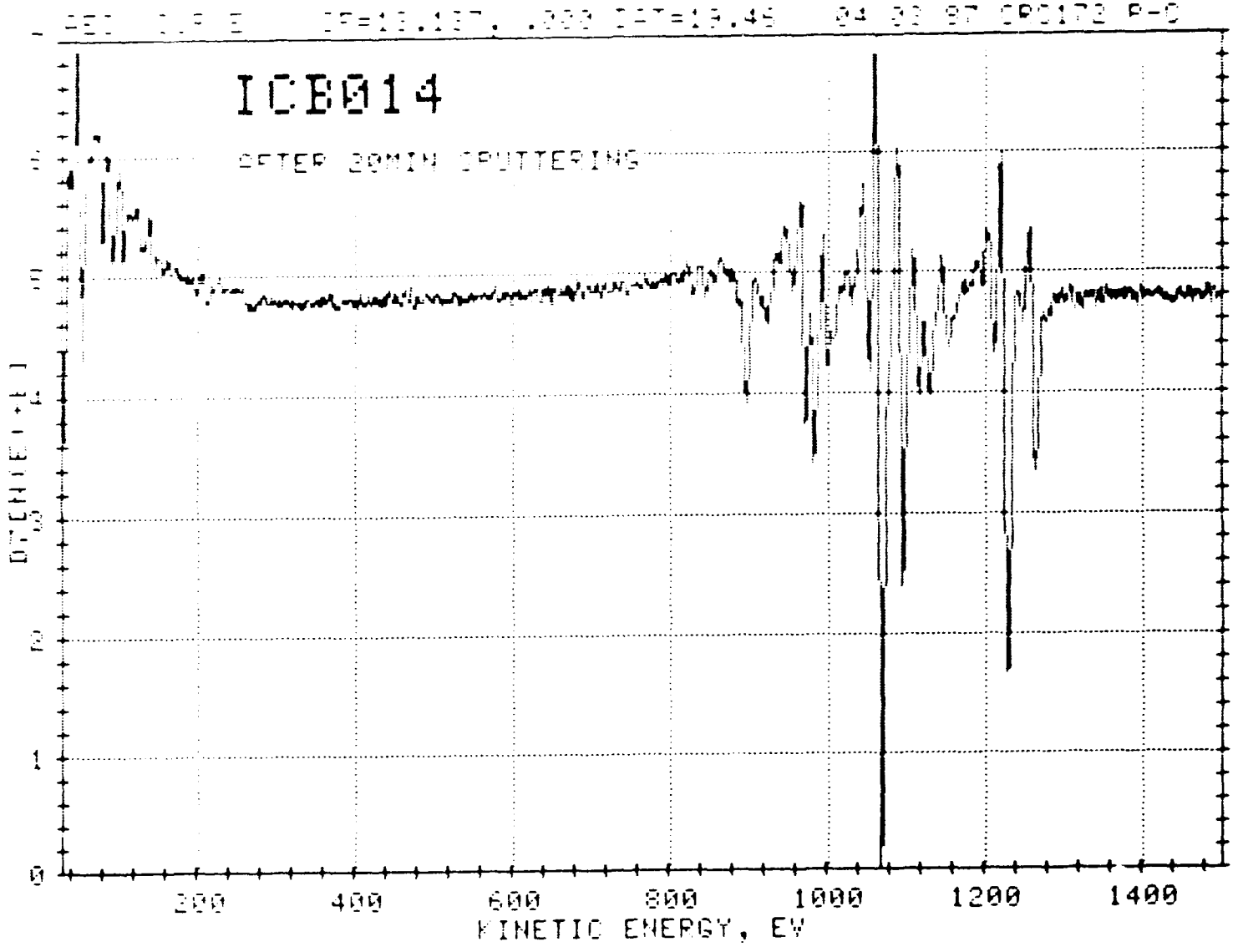
TEM Micrograph of Cross-Section

x36,000

x80,000

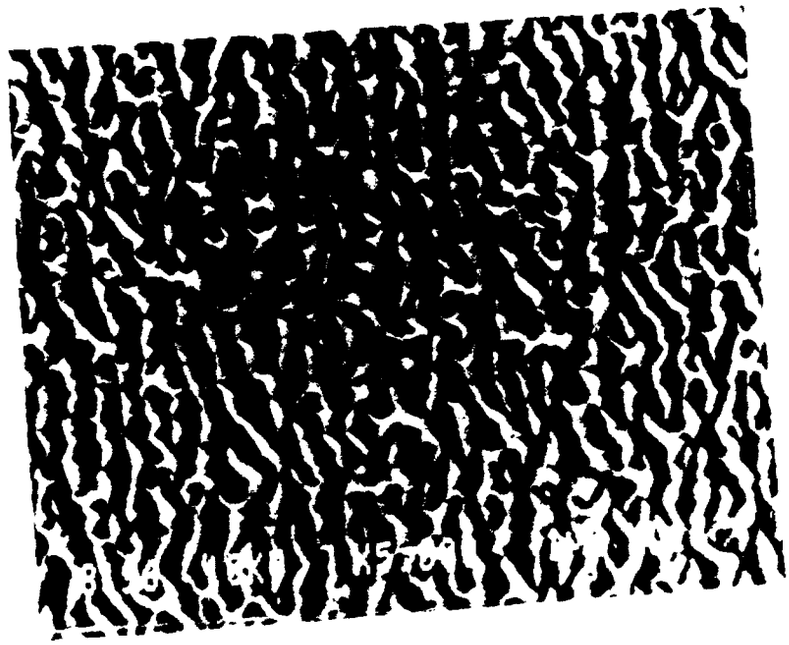
TEM Micrographs in Direction Normal to Surface


ICB014
BEFORE SPUTTERING
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
3
4
5

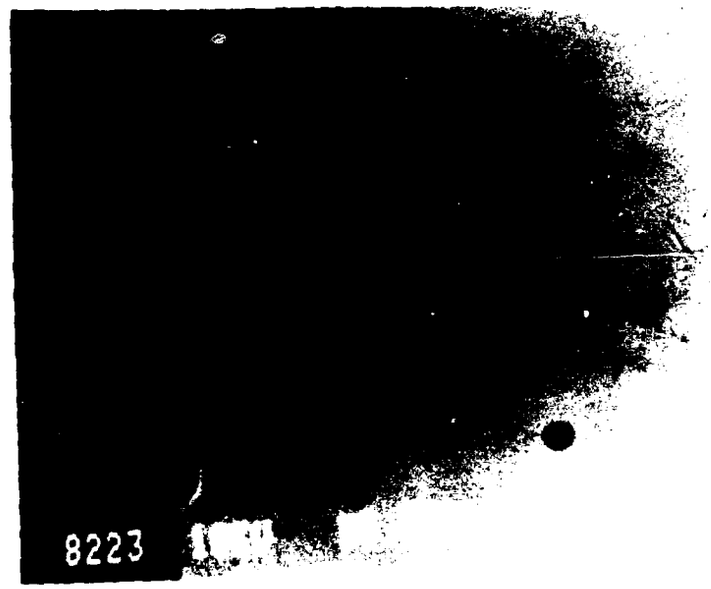

ICB014
AFTER 30MIN SPUTTERING
DERIVATIVE
0
1
2
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 015

SAMPLE #015



Film
Surface



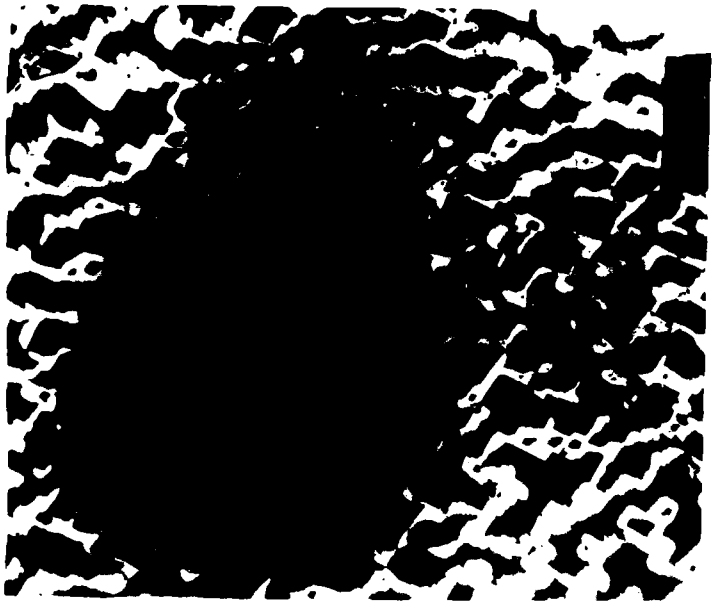
Cleave
Cross
Section

Film
Thickness
Approximately ?

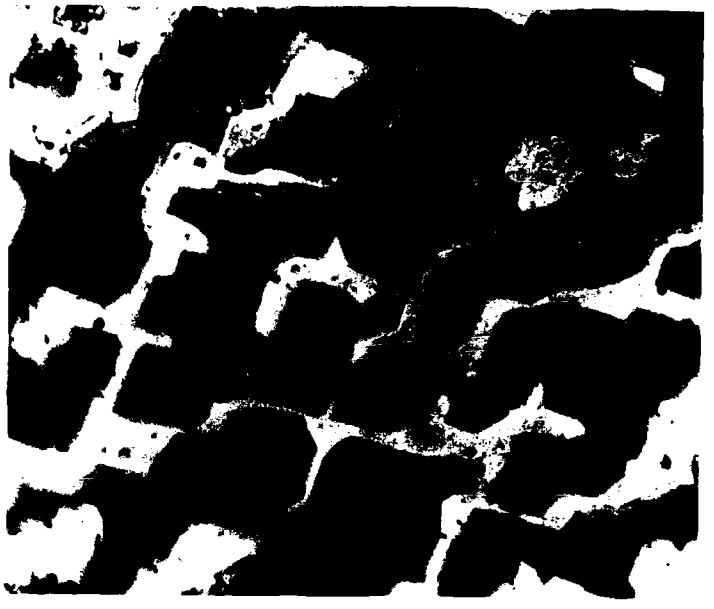
SAMPLE #015

ECP
(Film)

SAMPLE #015



x6,000



x17,000

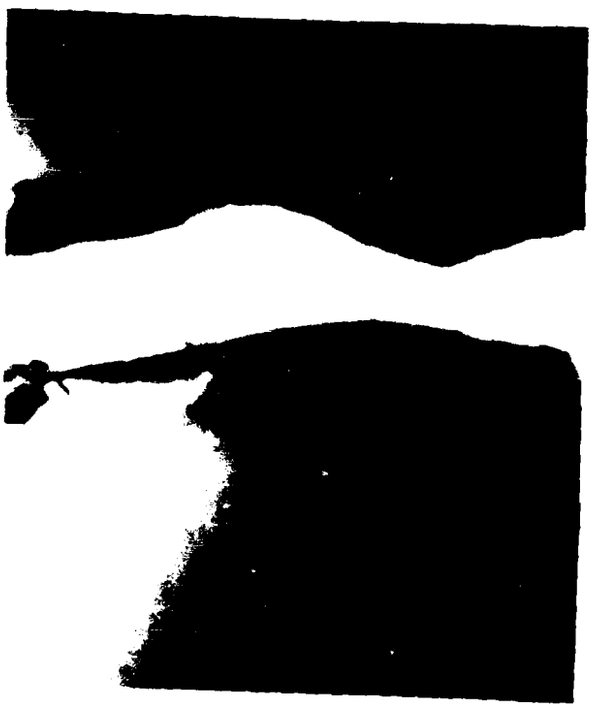
x36,000

x80,000

TEM Micrographs in Direction Normal to Surface

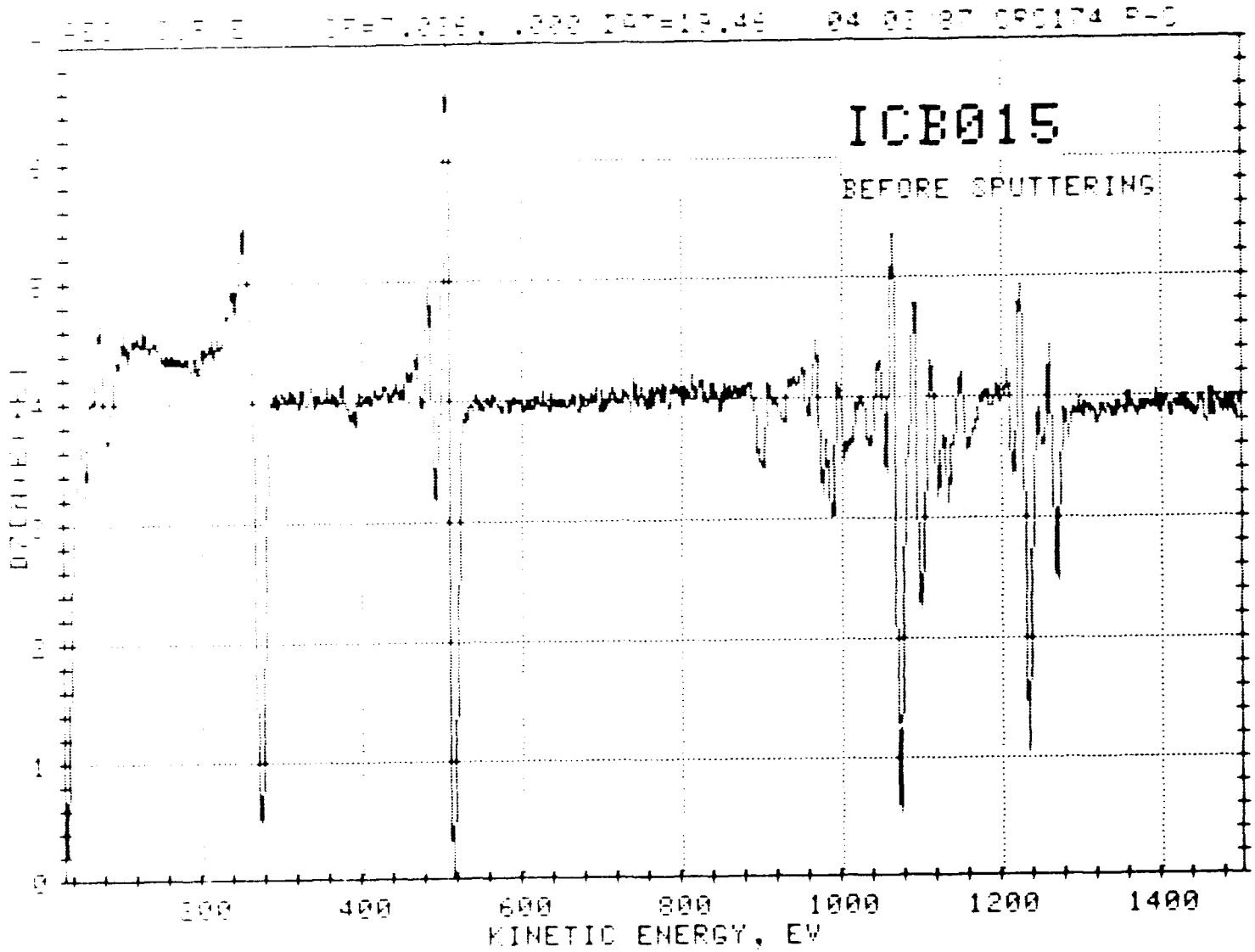
SAMPLE #015

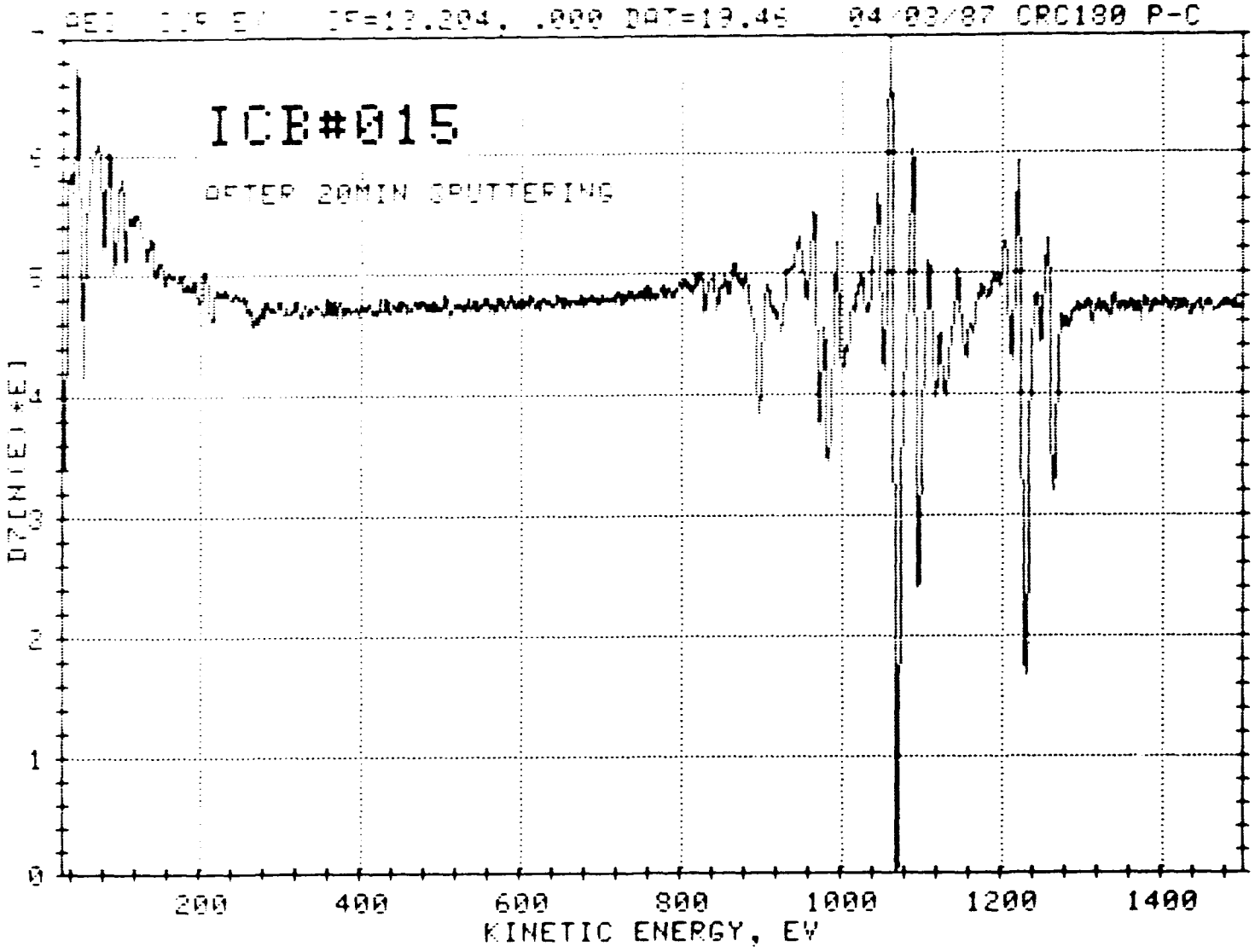
x60.000



x60.000

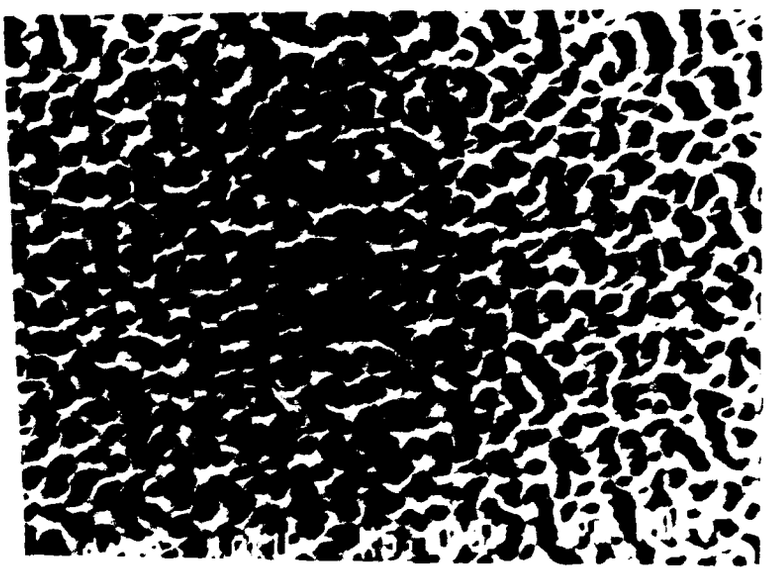
TEM Micrographs of Cross-Section


ICB015
BEFORE SPUTTERING
0
1
300
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

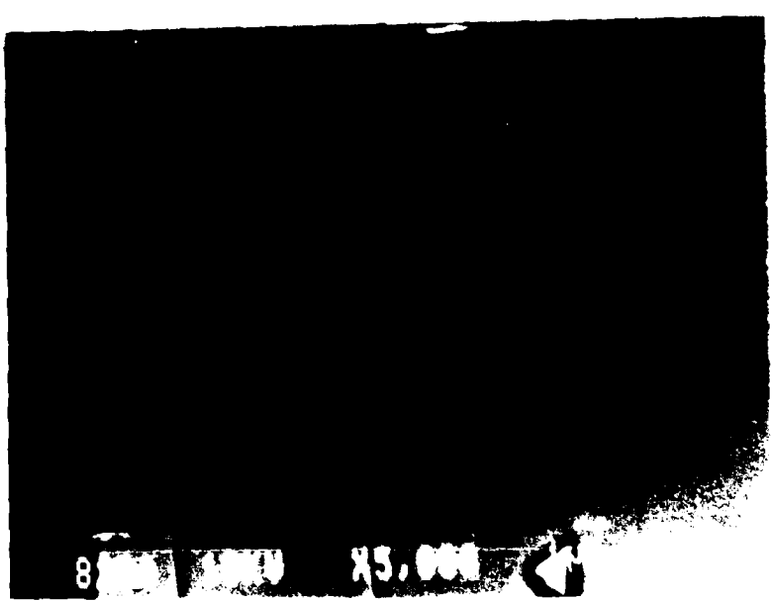

ICB#015
AFTER 20MIN SPUTTERING
DN(E)/N(E)
0
1
2
3
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 016

SAMPLE #016



Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

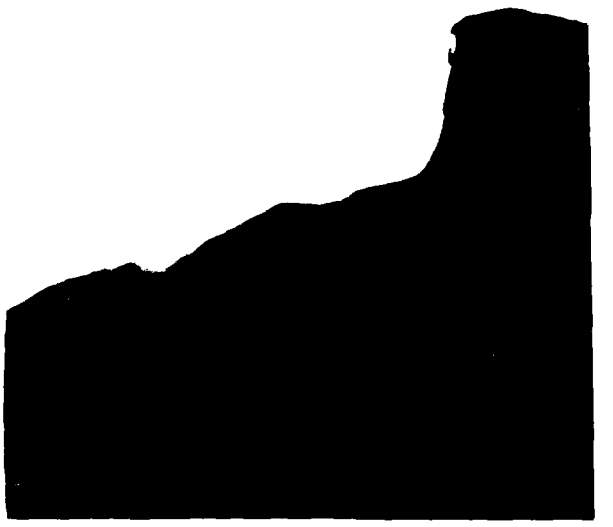
SAMPLE #016

ECP
(Film)

SAMPLE #016

x36,000

TEM Micrographs of Cross-Section



x60,000

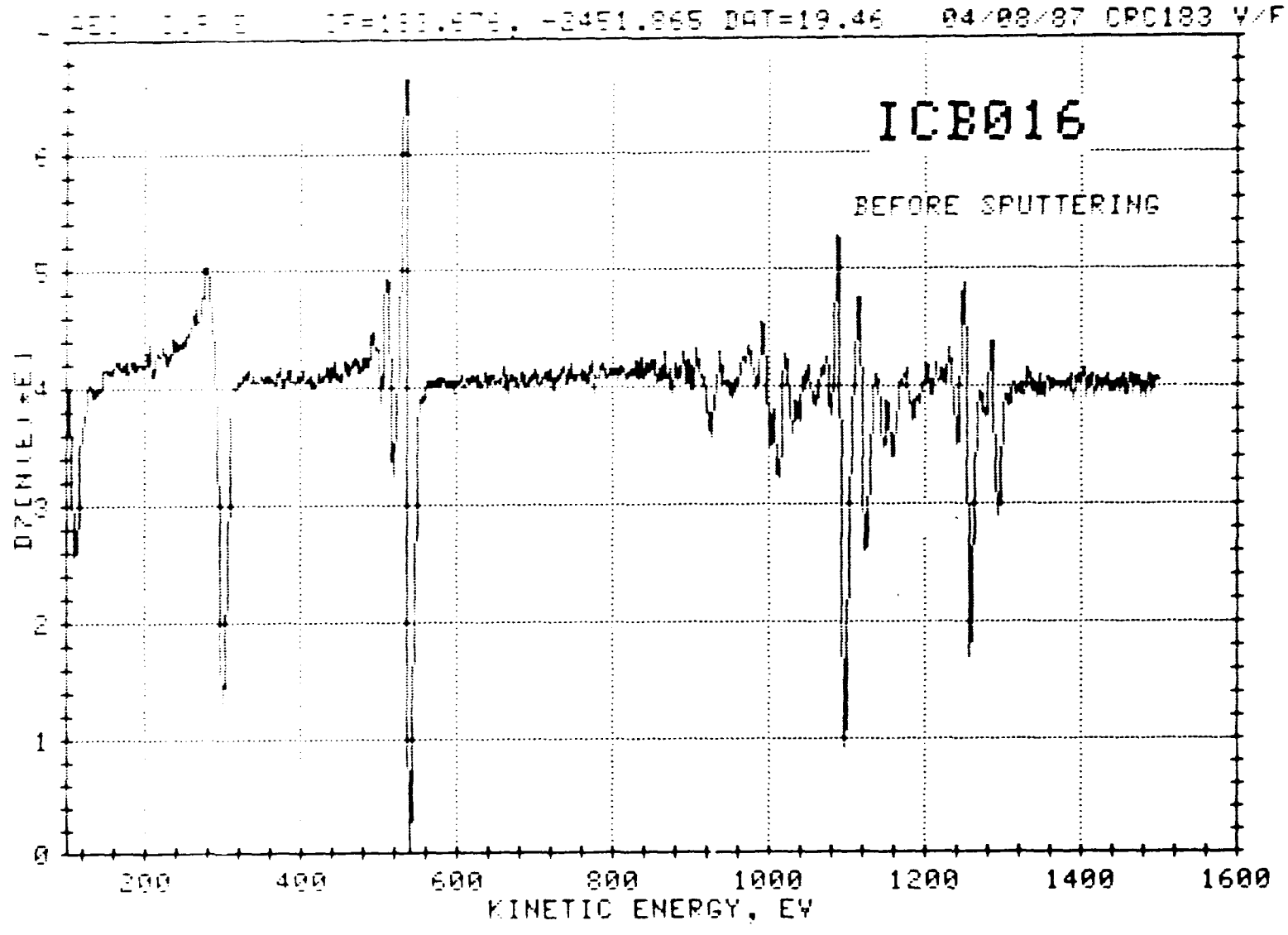
SAMPLE #016

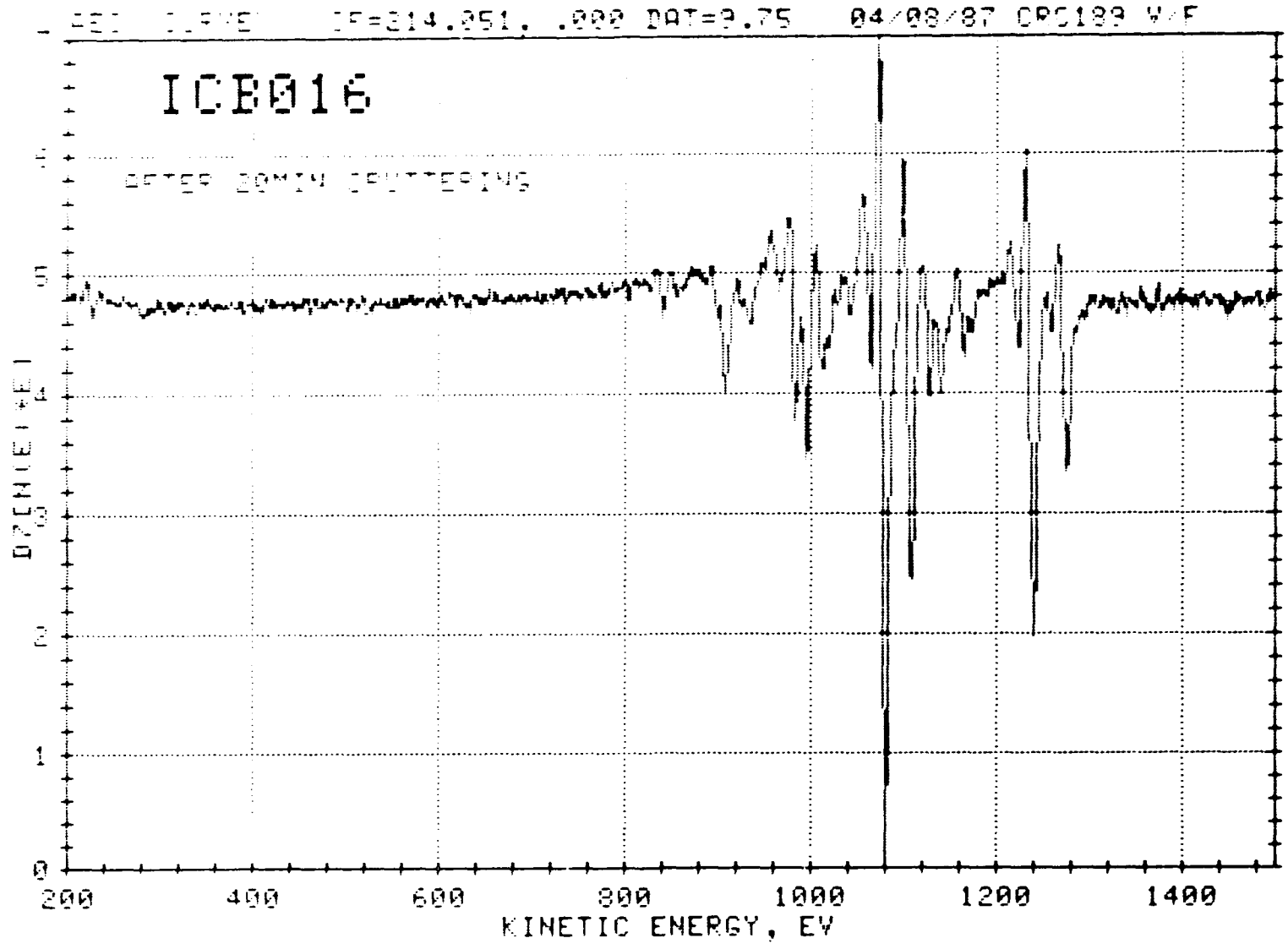
x17,000

x36,000

x80,000

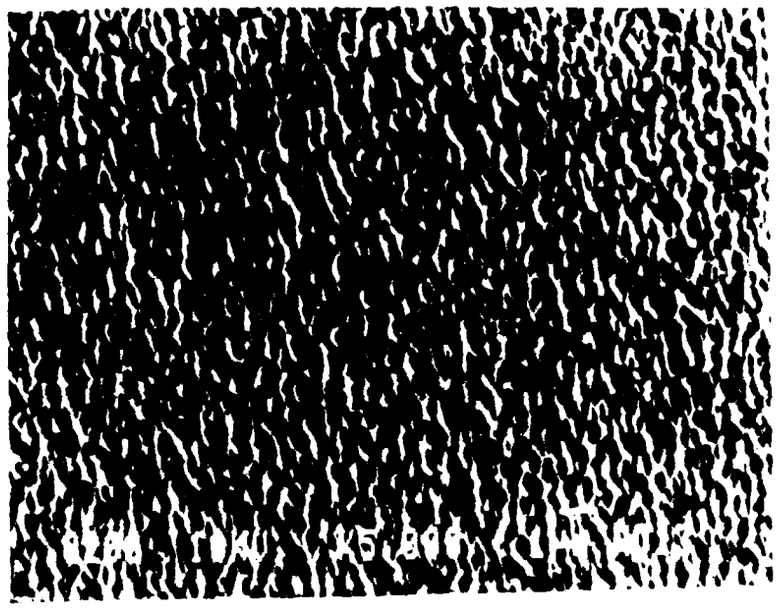
TEM Micrographs in Direction Normal to Surface


ICB016
BEFORE SPUTTERING
04/08/87 CRC183 V/F
DP(N(E)*E)
0
1
200
400
600
800
1000
1200
1400
1600
KINETIC ENERGY, EV

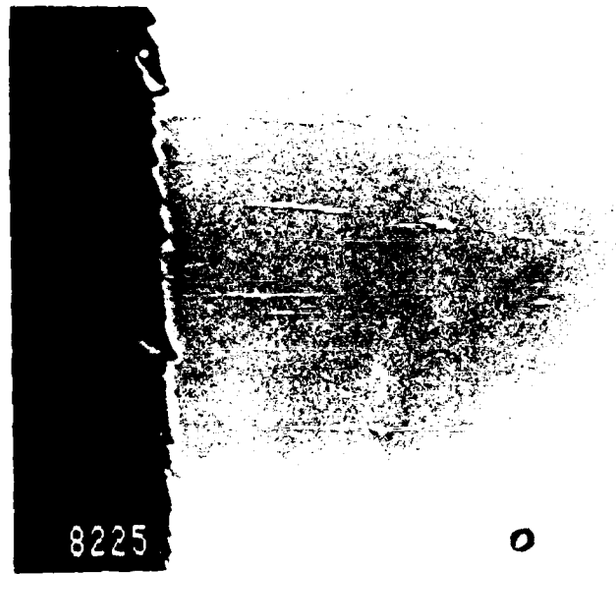

IF=314.051, .000 DAT=9.75 04/08/87 CPC189 W/F
ICB016
AFTER 20MIN SPUTTERING
DERIVATIVE
0
1
2
3
4
5
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 017

SAMPLE #017



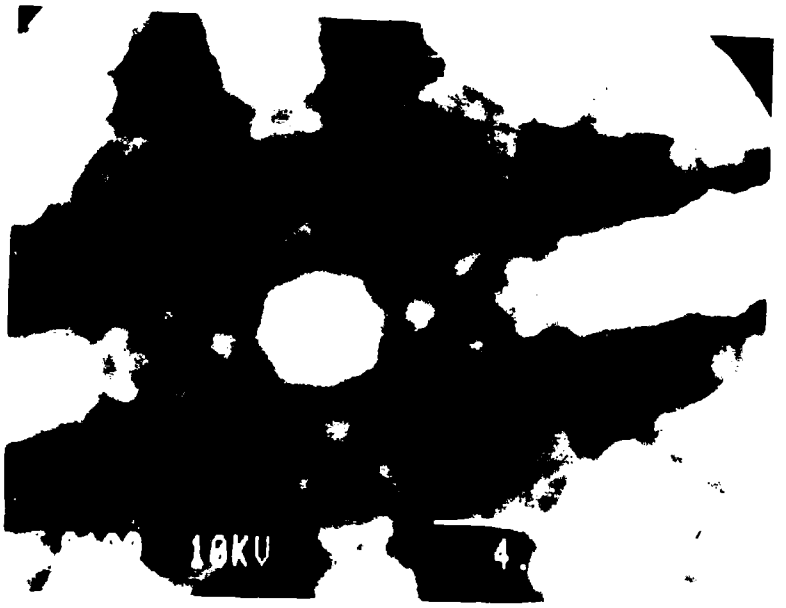
Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

SAMPLE #017



SAMPLE #017

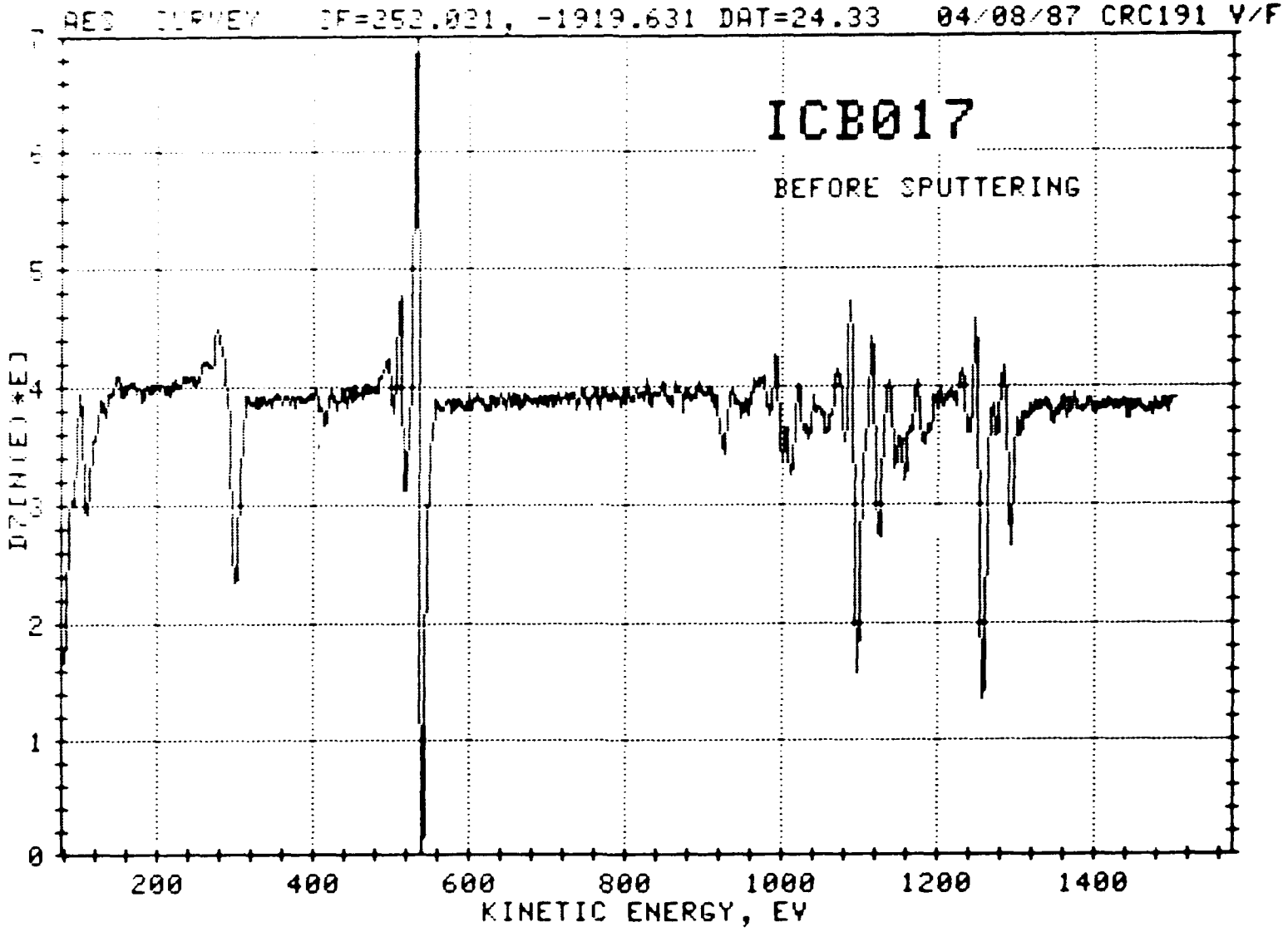
x80,000

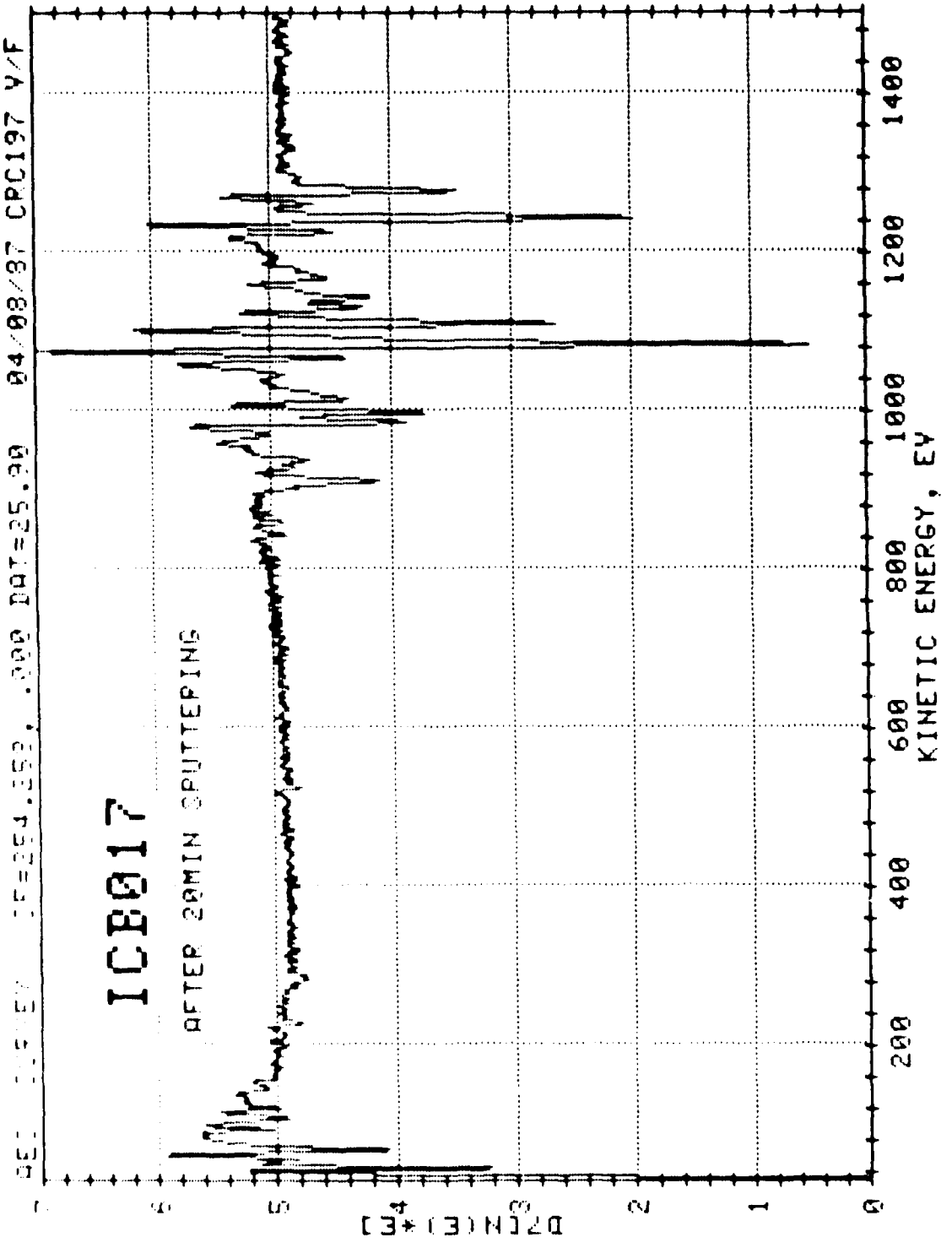
TEM Micrograph of Cross-Section

x36,000

x80,000

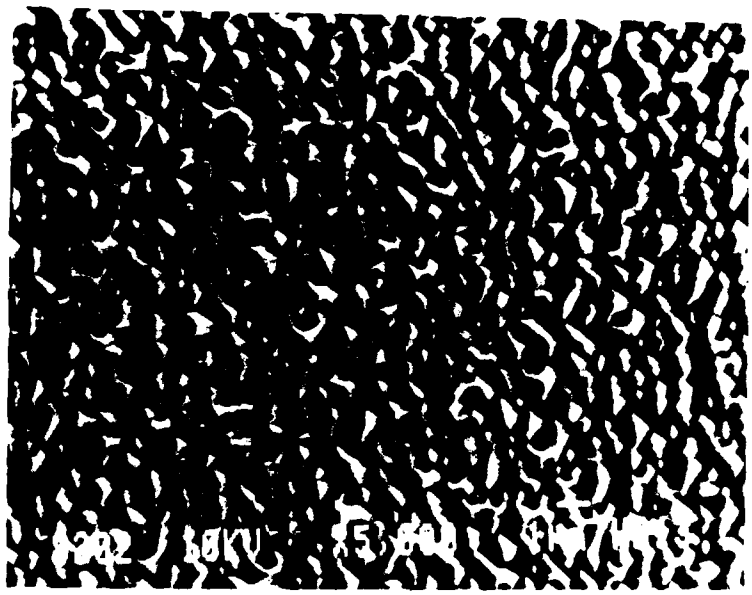
TEM Micrographs in Direction Normal to Surface


AES SURVEY DF=252.021, -1919.631 DAT=24.33 04/08/87 CRC191 V/F
ICB017
BEFORE SPUTTERING
D7[N(E)*E]
0
1
2
3
4
5
6
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

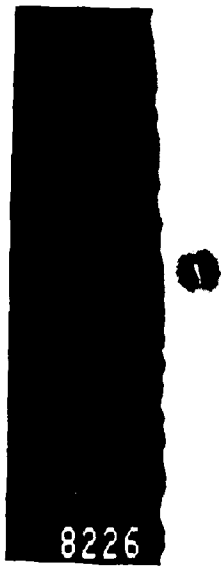

ICE017
AFTER 20MIN SPUTTERING
04/08/87 CPC197 V/F
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
3
4
5
6
D2[N(E)*E]

RUN NO. 018

SAMPLE #018



Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

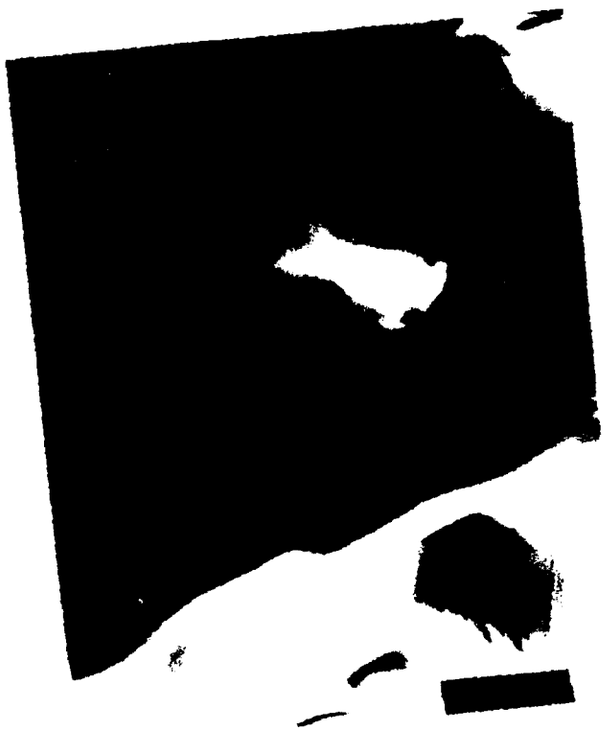
SAMPLE #018

ECP
(Film)

SAMPLE #018

x22,000

TEM Micrographs in Direction Normal tc Surface



x80,000

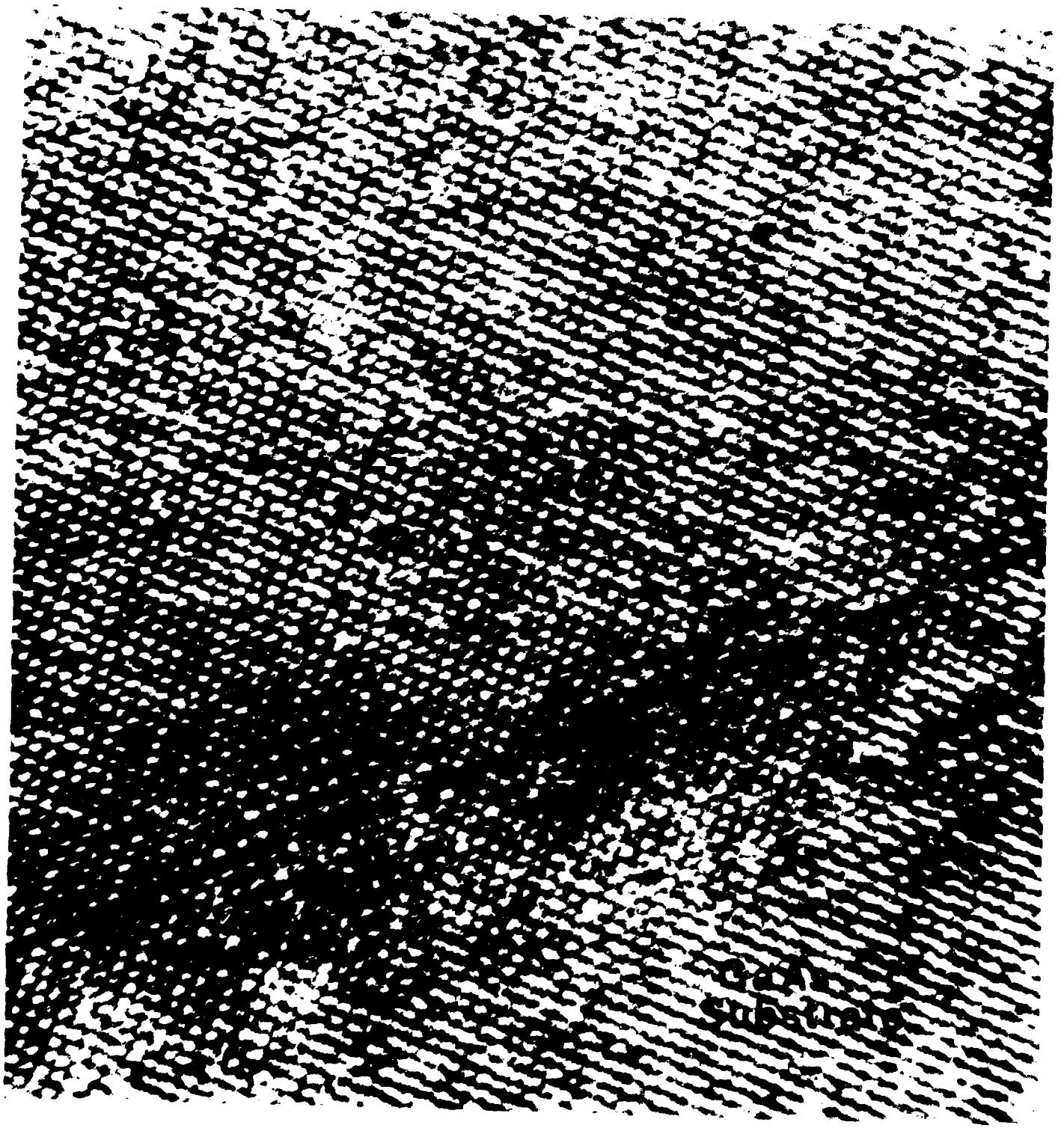
SAMPLE #018

x22,000

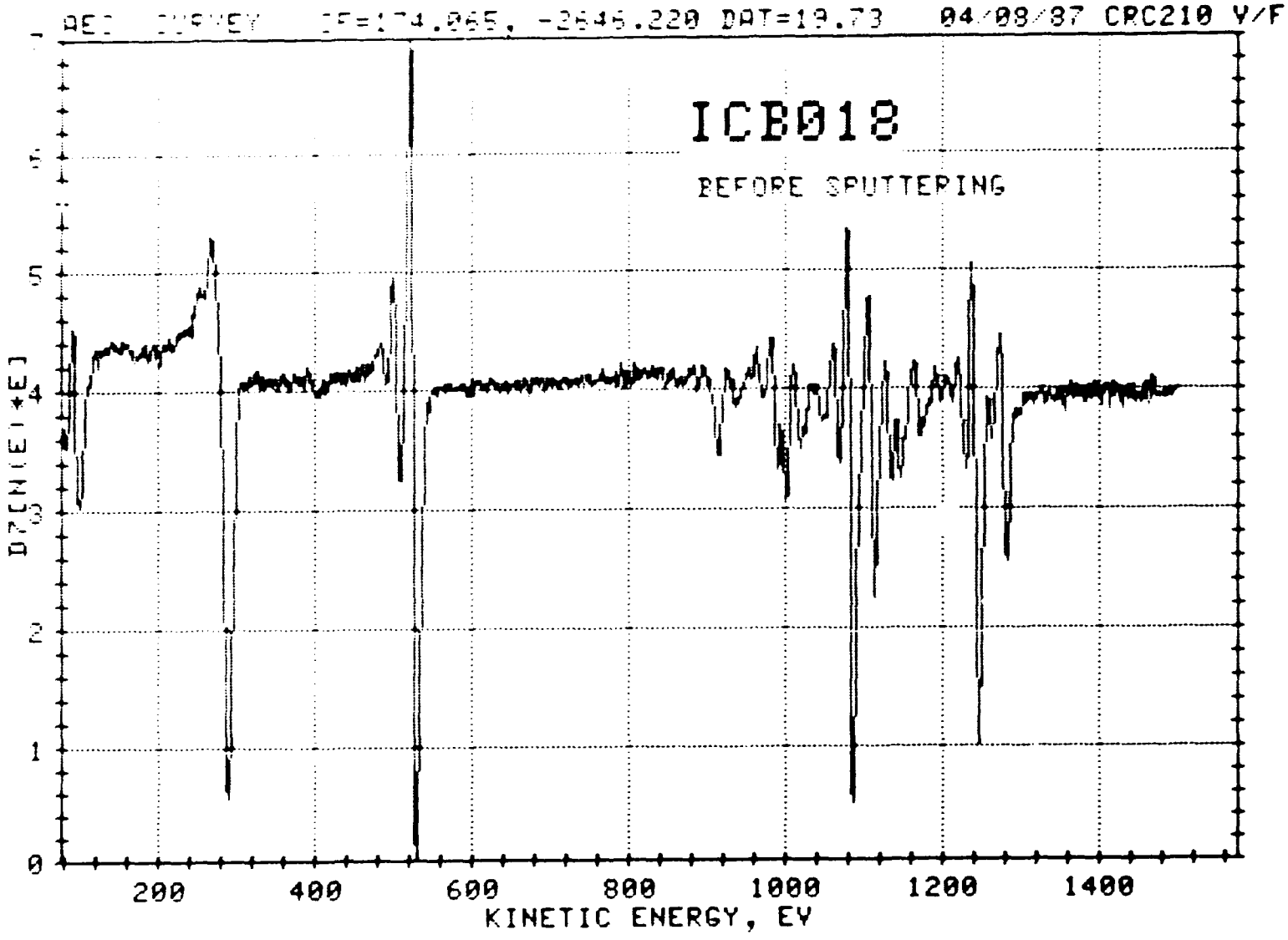
x60,000

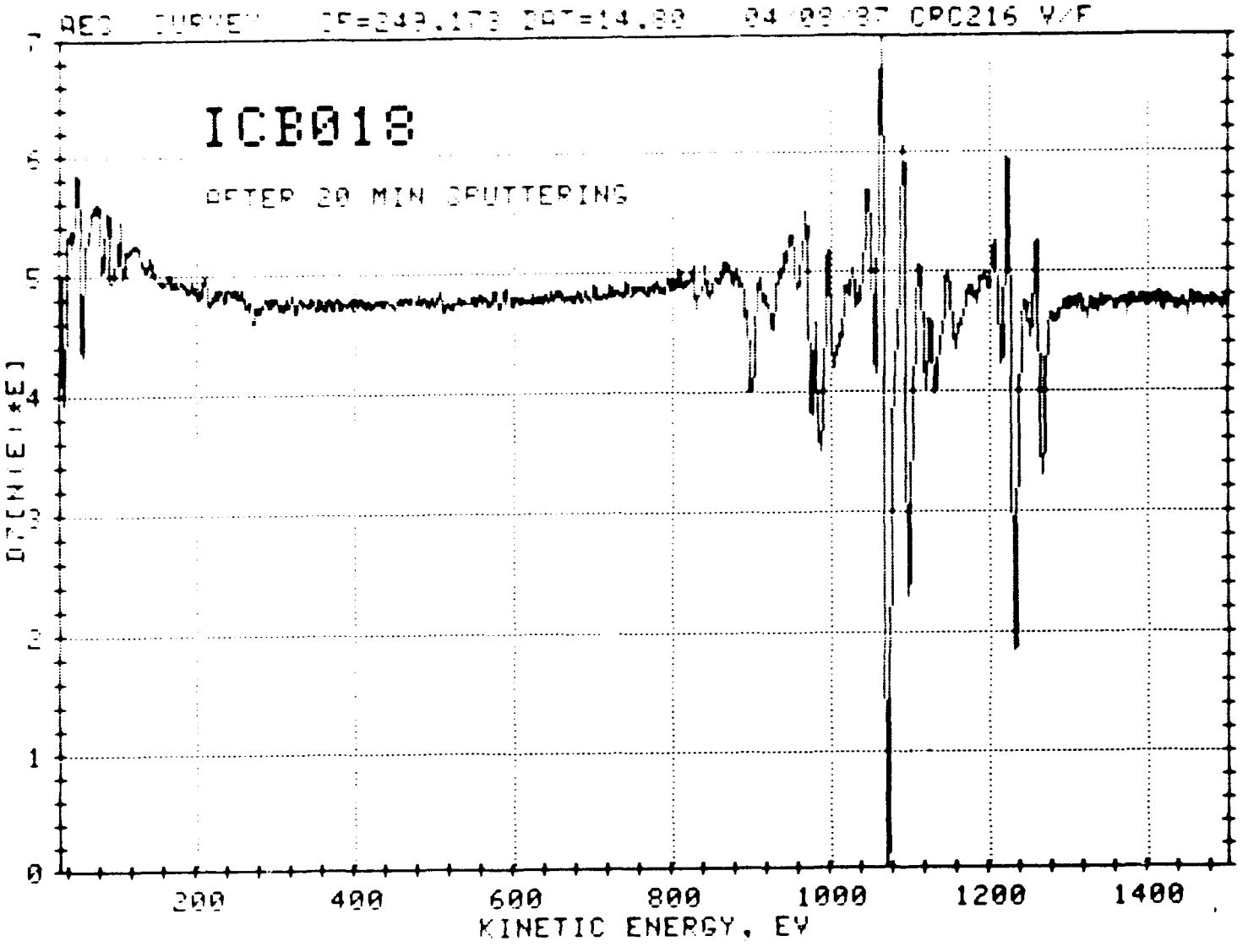
x130,000

SAMPLE #018



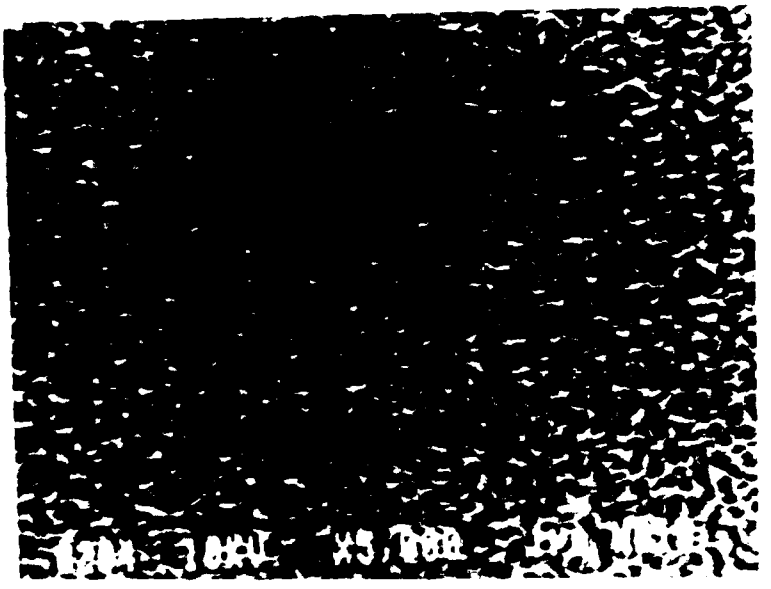
High Resolution TEM Micrograph of GaAs/CaFs Interface

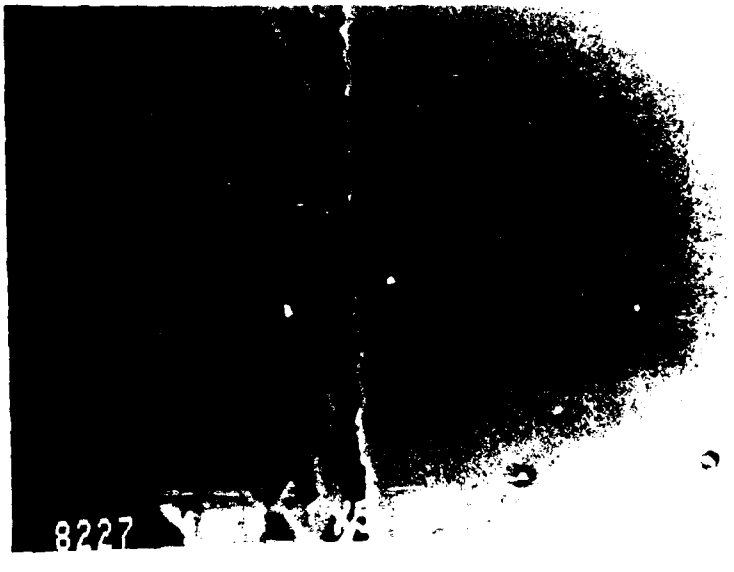

ICB018
BEFORE SPUTTERING
04/08/87 CRC210 Y/F
0
1
5
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400


ICB018
AFTER 30 MIN SPUTTERING
D(N(E)*E)
0
1
2
3
4
5
6
7
200
400
600
800
1000
1200
1400
KINETIC ENERGY, EV

RUN NO. 019

SAMPLE #019

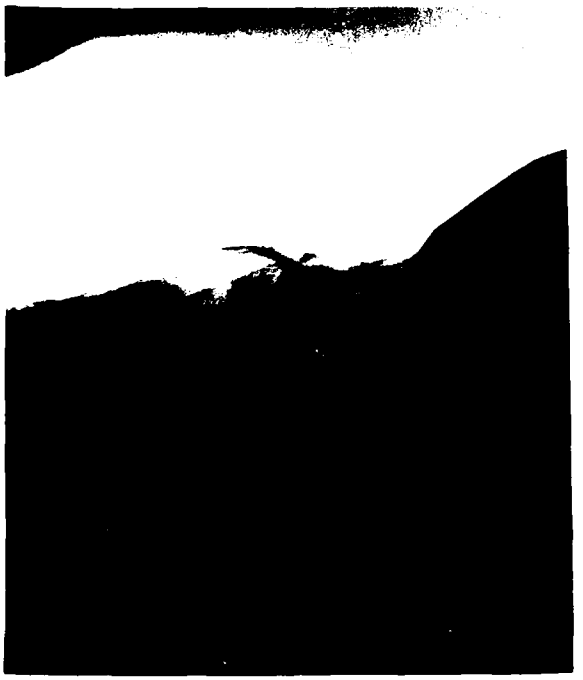




SAMPLE #019

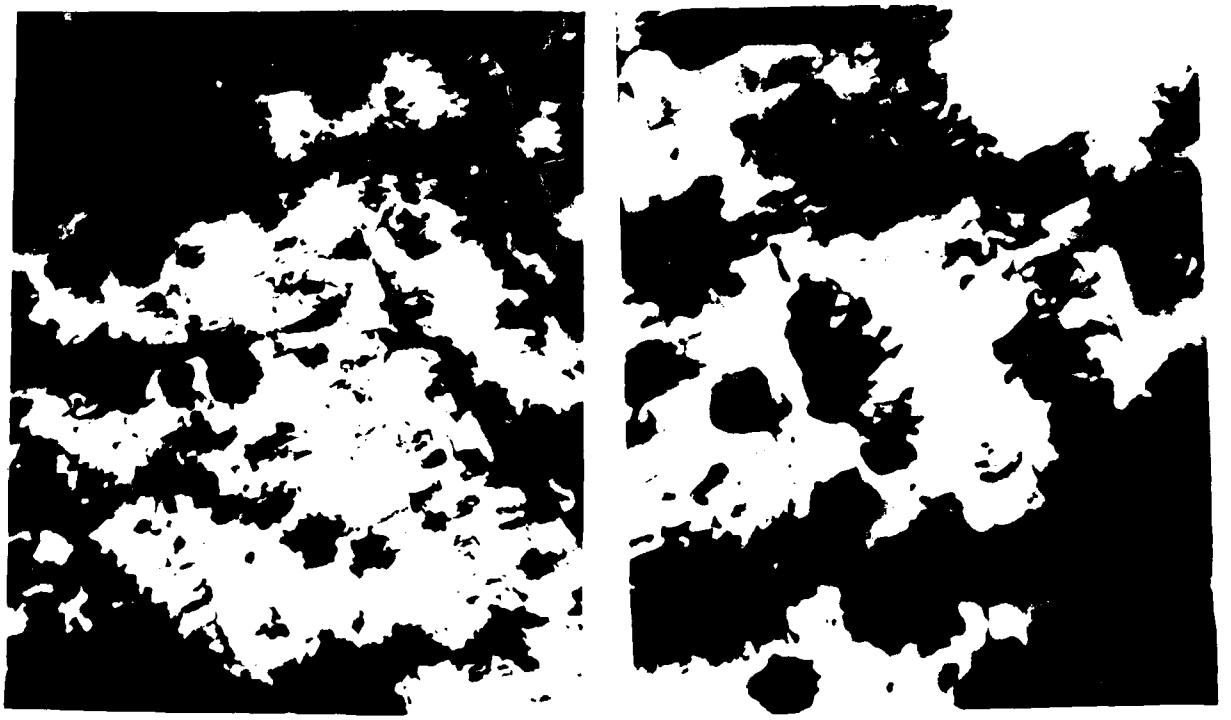
ECP
(Film)

SAMPLE #019



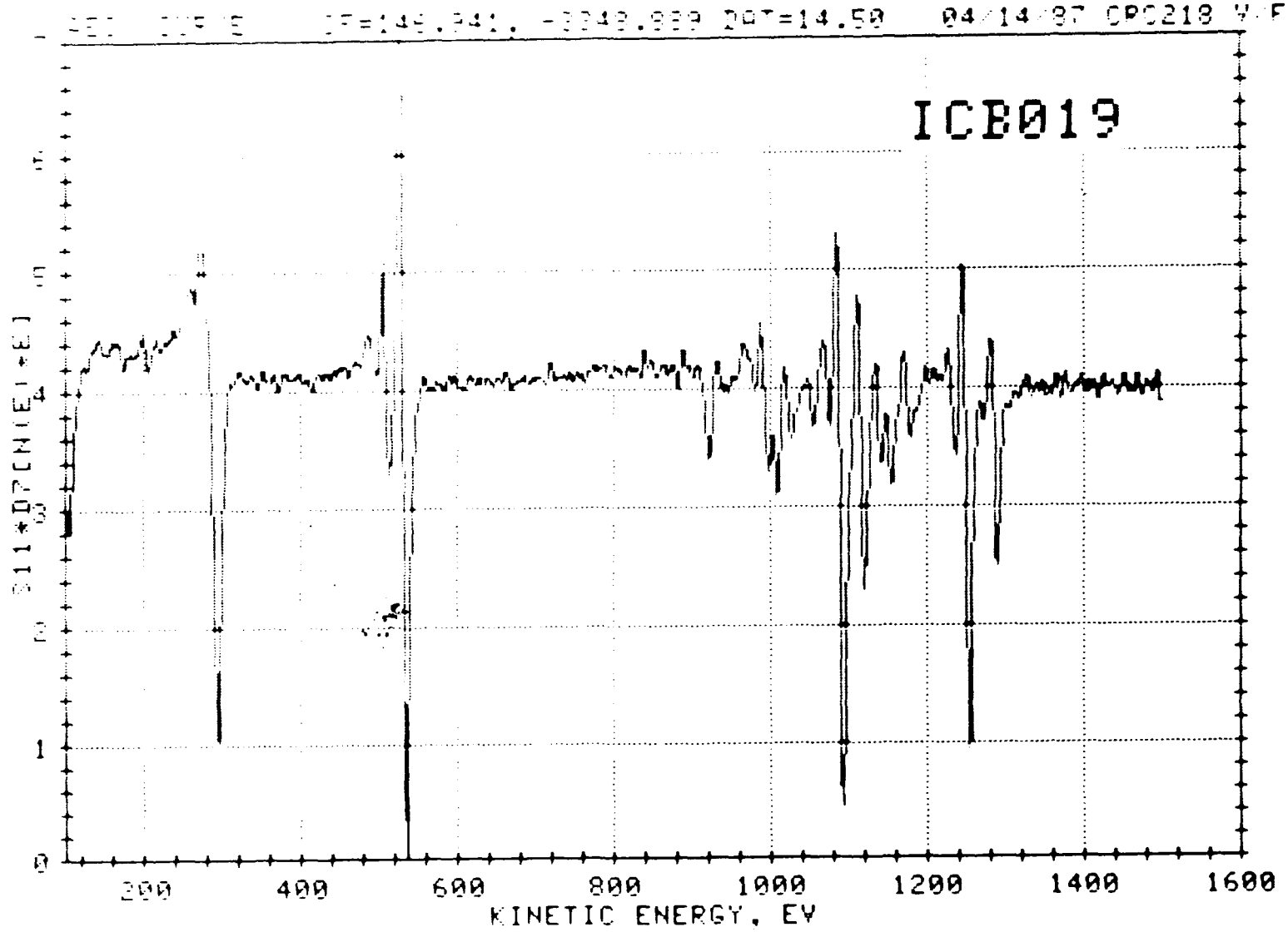
x100,000

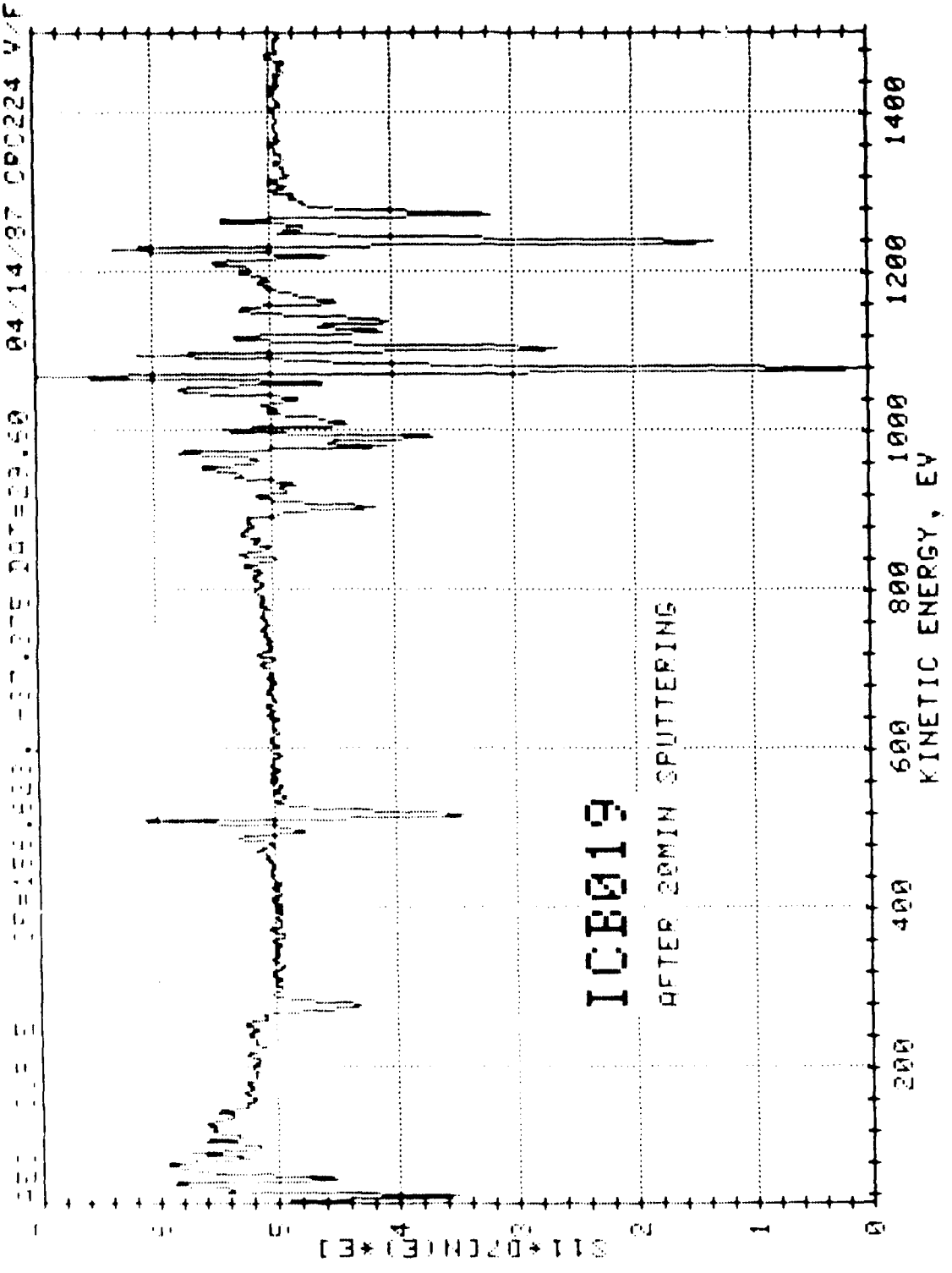
TEM Micrograph of Cross-Section



x36,000

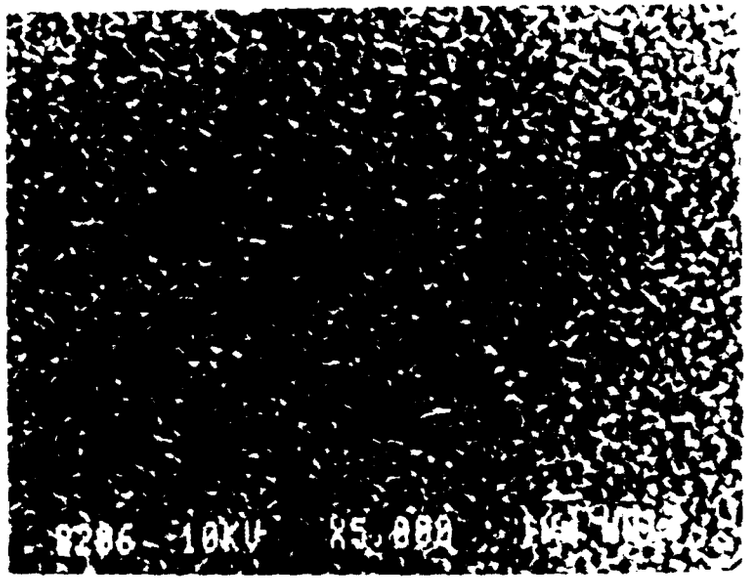
TEM Micrographs in Direction Normal t Surface


ICB019
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
1600
0
1
4
5

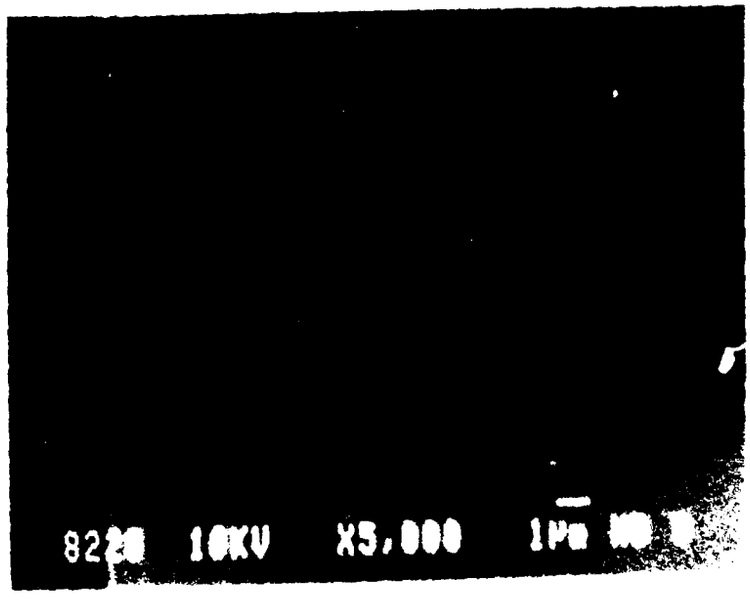

04/14/87 CPC224 V/F
ICB019
AFTER 20MIN SPUTTERING
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
3
4

RUN NO. 020

SAMPLE #020



Film
Surface



Cleave
Cross
Section

Film
Thickness
Approximately ?

SAMPLE #020

x80,000

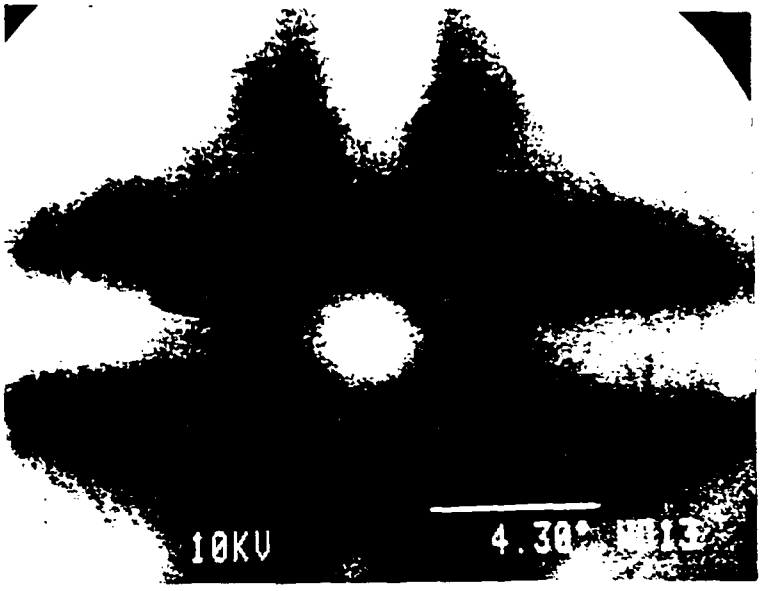
TEM Micrograph of Cross-Section

x36,000

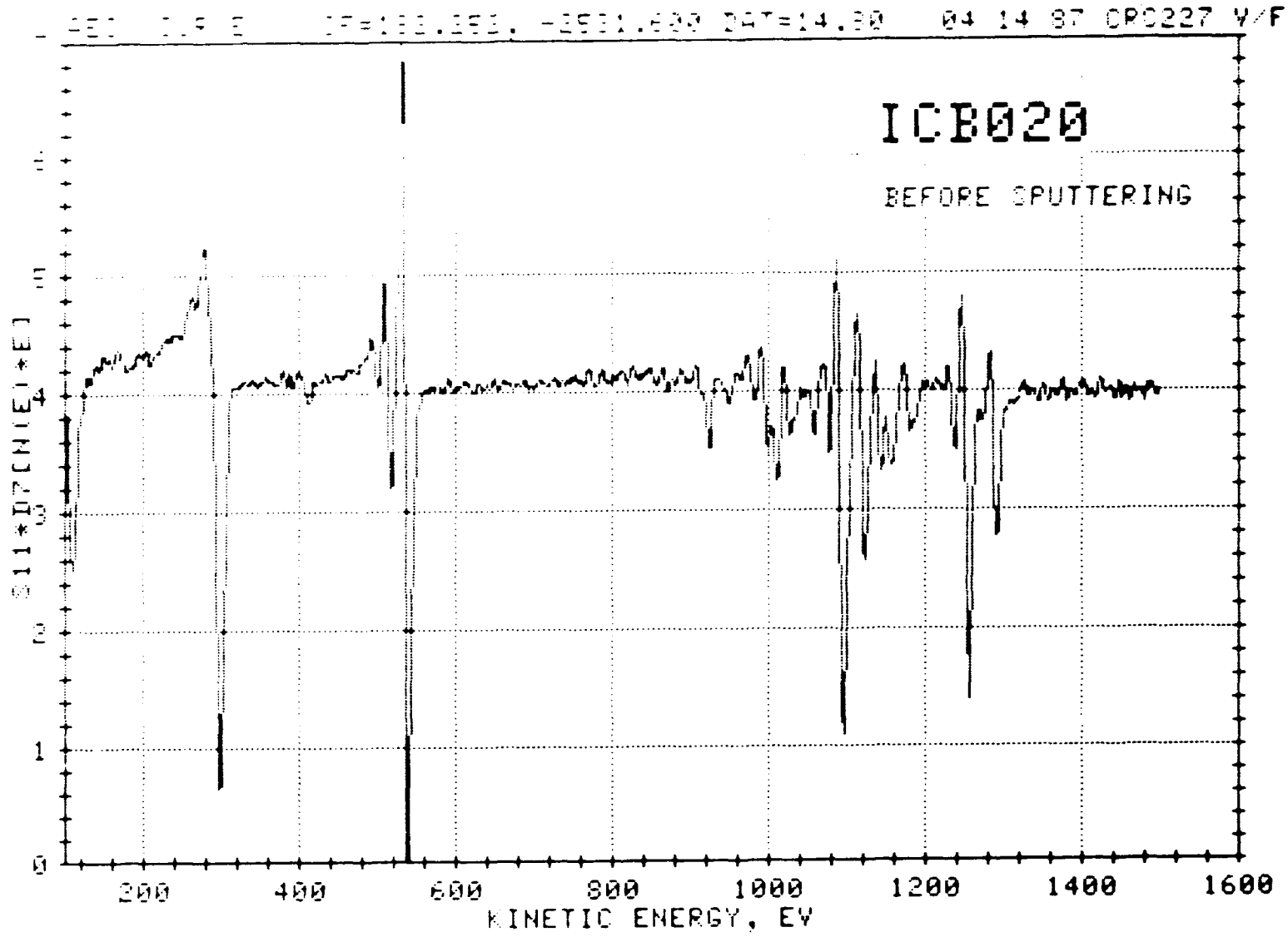
x80,000

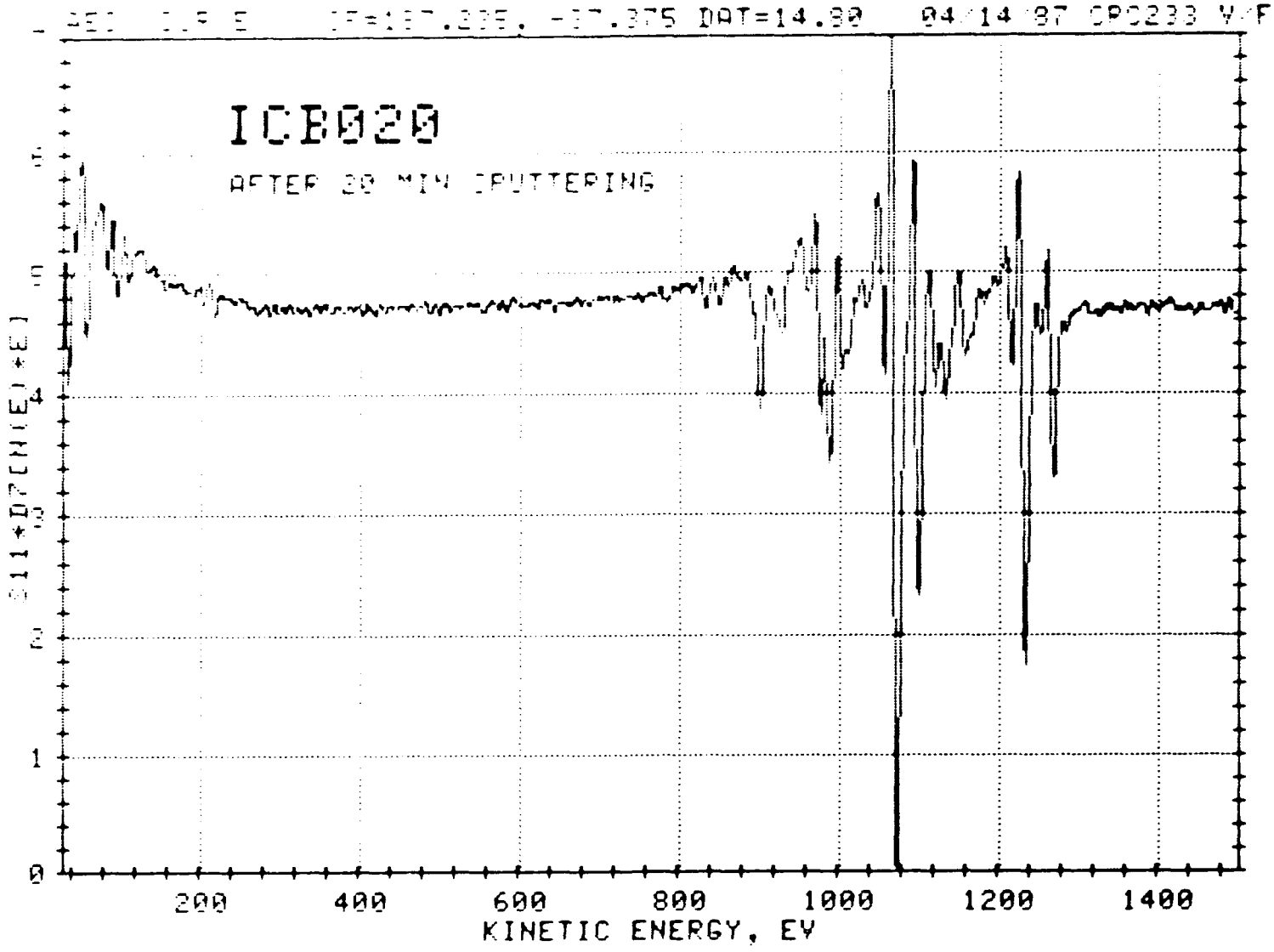
TEM Micrographs in Direction Normal to Surface

SAMPLE #020



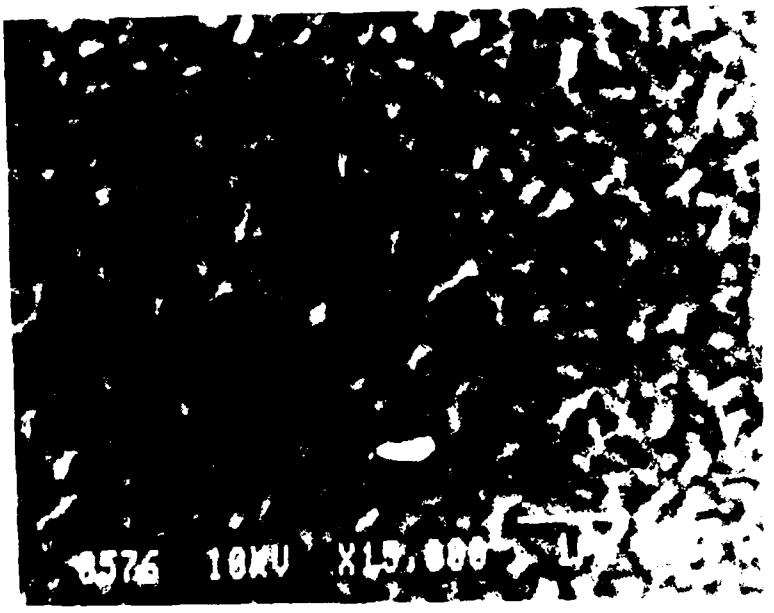
ECP
(Film)


ICB020
BEFORE SPUTTERING
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
1600
0
1
3
4
5
6

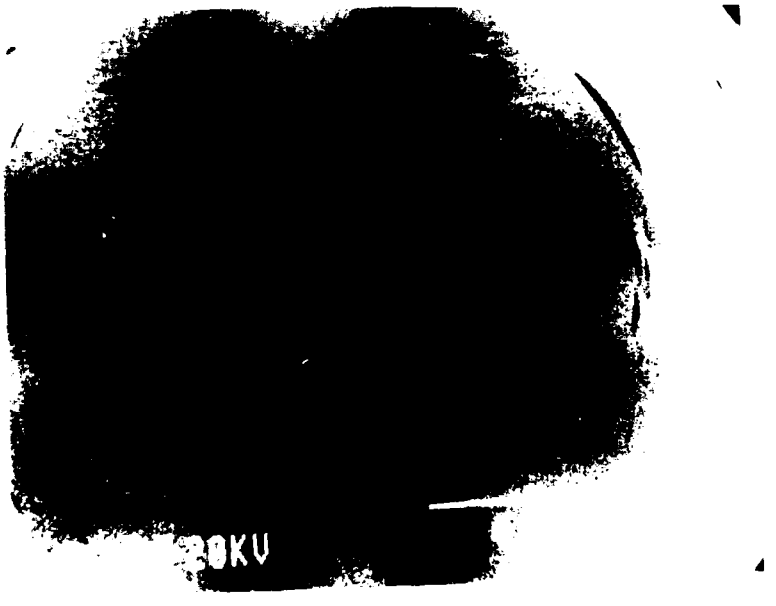

ICB020
AFTER 30 MIN SPUTTERING
04/14/87
KINETIC ENERGY, EV
200
400
600
800
1000
1200
1400
0
1
2
3
4
5

RUN NO. 021

SAMPLE #021



SEM Micrograph of Film Surface

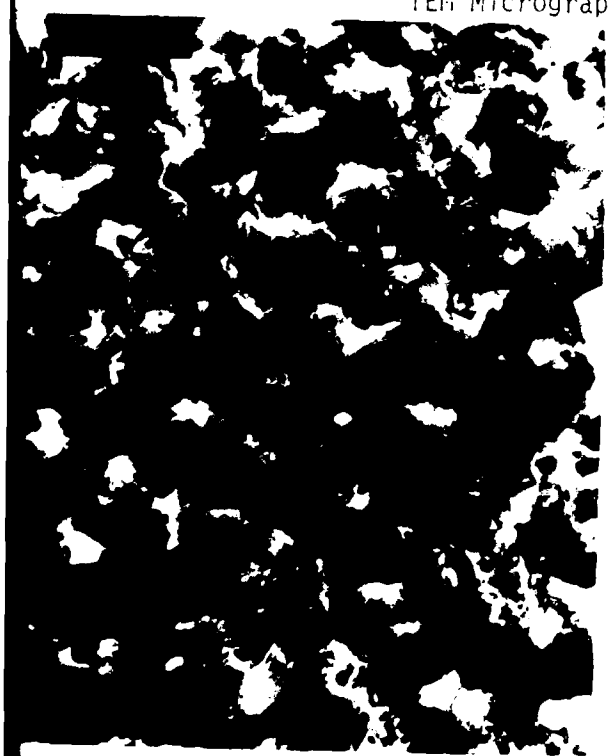


Electron Channeling Pattern from Film Surface

SAMPLE #021

x130,000

TEM Micrograph of Cross-Section



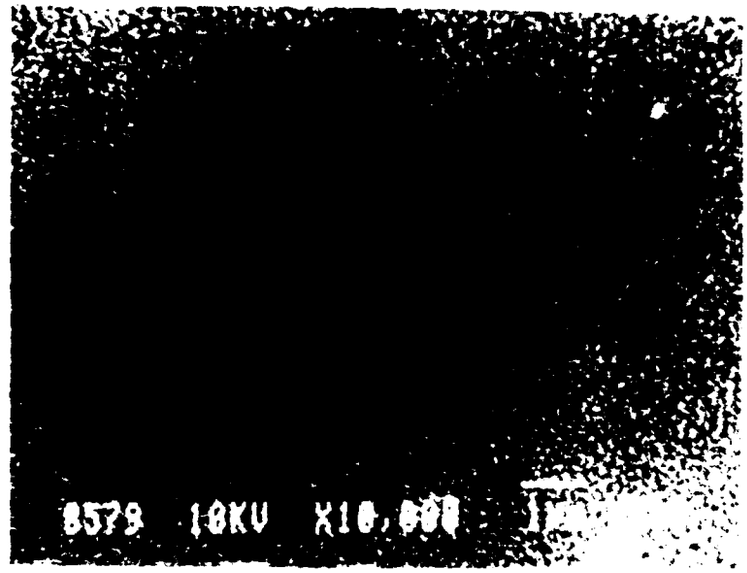
x36,000

x80,000

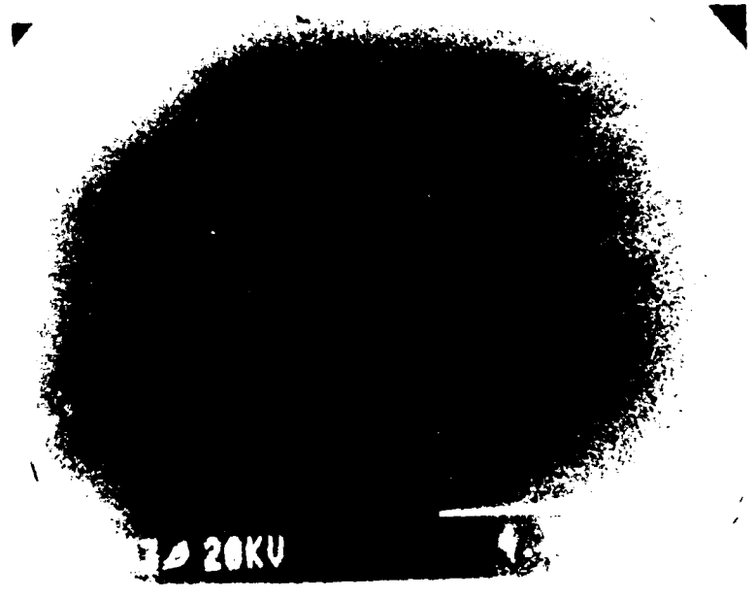
TEM Micrographs in Direction Normal to Surface

RUN NO. 022

SAMPLE #022



SEM Micrograph of Film Surface

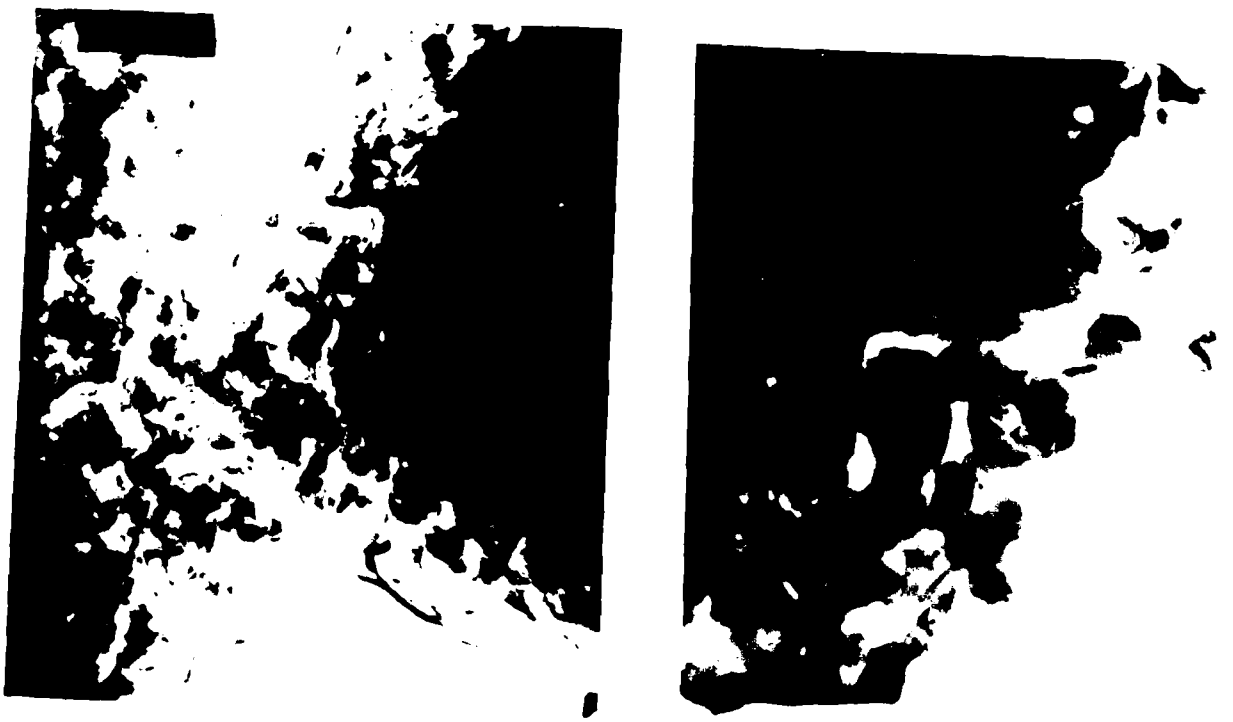


Electron Channeling Pattern from Film Surface

SAMPLE #022

x100,000

TEM Micrograph of Cross-Section



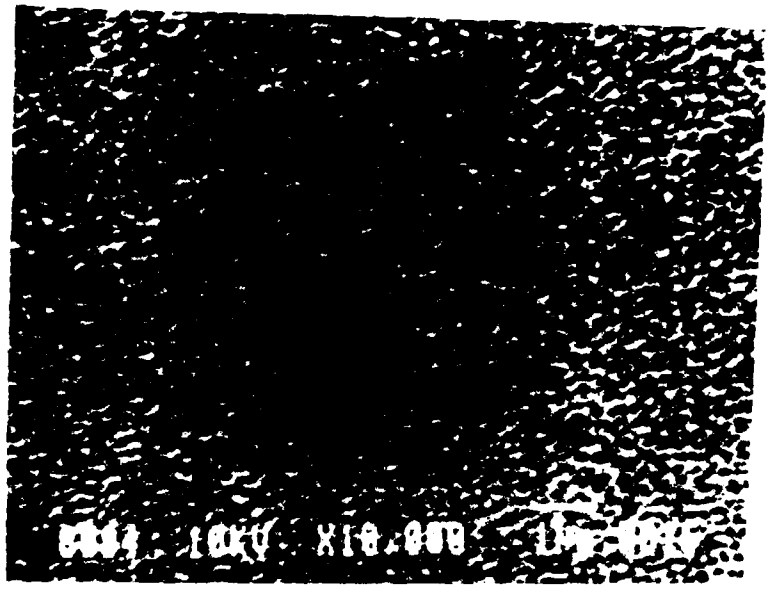
x36,000

x80,000

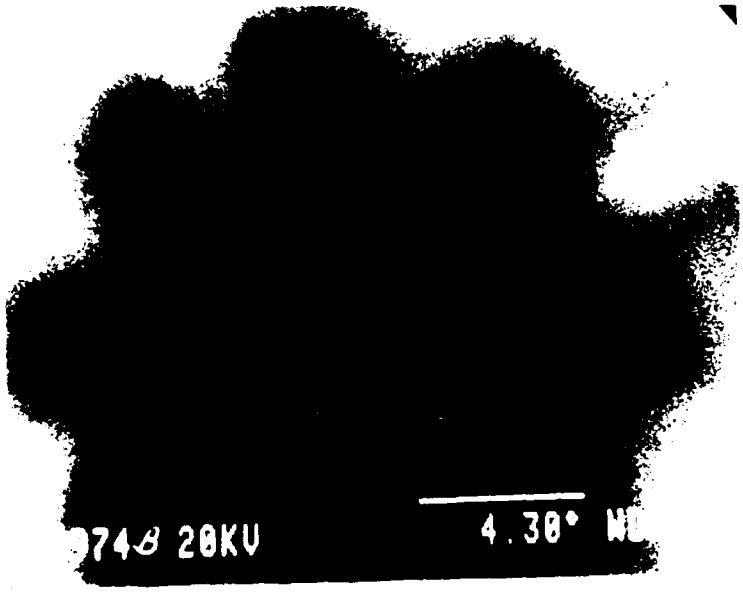
TEM Micrographs in Direction Normal to Surface

RUN NO. 023

SAMPLE #023



SEM Micrograph of Film Surface



Electron Channeling Pattern from Film Surface

SAMPLE #023

x80,000

TEM Micrograph of Cross-Section

SAMPLE #023

x2,800

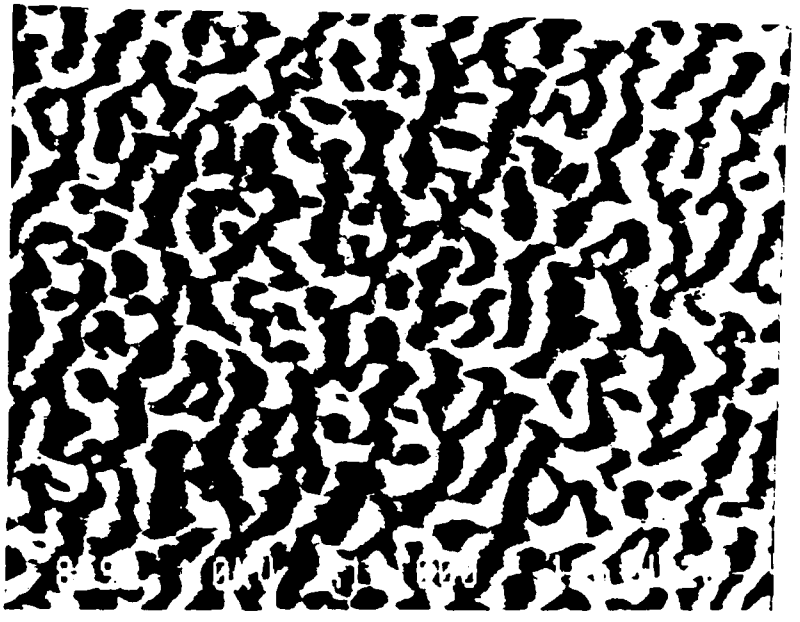
x36,000

x170,000

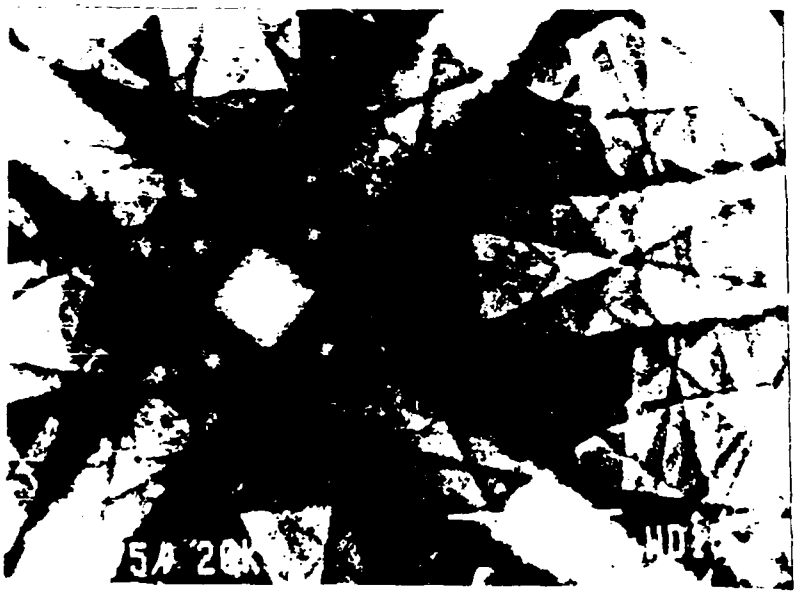
TEM Micrographs in Direction Normal to Surface

RUN NO. 024

SAMPLE #024



SEM Micrograph of Film Surface

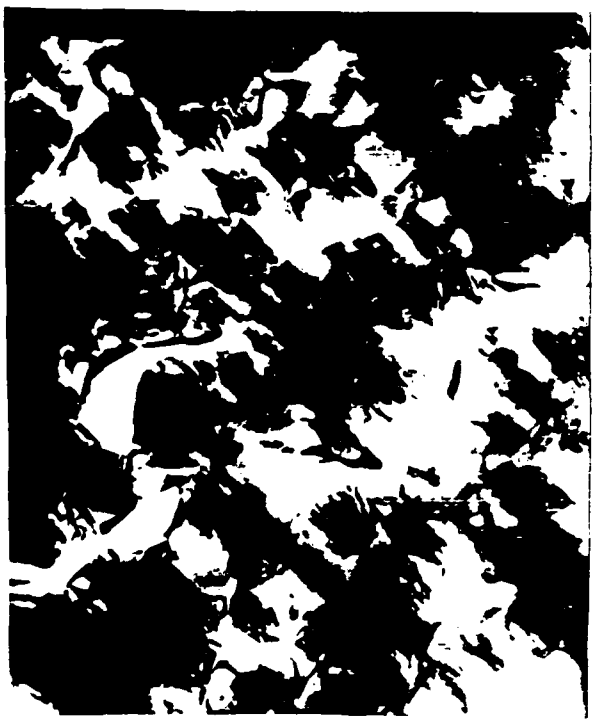


Electron Channeling Pattern from Film Surface

SAMPLE #024

x4,135

TEM Micrograph of Cross-Section



x36,000

x80,000

TEM Micrographs in Direction Normal to Surface